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**REVISION 2**

NAVAL SHIPS' TECHNICAL MANUAL

CHAPTER 254

# CONDENSERS, HEAT EXCHANGERS, AND AIR EJECTORS

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# CHAPTER 254

# CONDENSERS, HEAT EXCHANGERS, AND AIR EJECTORS

## SECTION 1.

## INTRODUCTION

### 254-1.1 EQUIPMENT

254-1.1.1 GENERAL. This chapter covers condensers, heat exchangers, and air ejectors. Section 1 provides background information on this equipment that will aid in understanding the more detailed information presented later.

254-1.1.2 HEAT EXCHANGERS. All shipboard heat exchangers transfer heat between fluids. The simplest and most common types transfer heat between two fluids, one hot and one cold. More complex arrangements are also possible, such as using one hot fluid to heat multiple cold fluids. The fluids can be liquids, gases, or vapors in any combination.

254-1.1.2.1 Shell-and-Tube Type. This chapter deals only with two types of heat exchangers: shell and tube and plate. Shell and tube heat exchangers are by far the most common type used by the Navy. They consist of a number of tubes inside a cylindrical shell. One fluid flows through the tubes, and the other flows around the outside of the tubes. Heat is transferred from the hot fluid, through the tube wall, and into the cold fluid. In most of the shell-and-tube heat exchangers discussed in this chapter, both fluids are liquids, although one of the fluids may be a gas or vapor. Section 3 gives more information on shell-and-tube heat exchangers.

254-1.1.2.2 Plate Type. Plate heat exchangers are not as common as the shell and tube type, but their use is growing. They consist of a stacked array of parallel plates, with gaskets to contain and direct the fluids. Hot and cold fluids flow in the spaces between alternate plates, with heat transfer through the plates. In plate heat exchangers both fluids are usually liquid. See Section 4 for more information. The advantages and disadvantages of shell-and-tube and plate heat exchangers are given in paragraph 254-4.1.6.

254-1.1.2.3 Other Types. The Navy uses many other types of heat exchangers. Some are similar to shell and tube types, but with some sort of extended surface (ribs or fins) on the outside of the tubes. These are normally used for liquid-gas applications (liquid in the tubes and gas outside), such as motor and generator air coolers or radiator-type oil coolers. Some distilling plants have double or triple tube heat exchangers, with small diameter tubes nested inside larger ones(NSTM Chapter 531, Volume 2, Desalination - Vapor Compression Distilling Plants) . These types of heat exchangers, however, are not discussed in this chapter.

254-1.1.3 STEAM CONDENSERS. Steam condensers are actually a type of shell-and-tube heat exchanger, but since they have important design and operational differences from other shell-and-tube units, they are discussed separately inSection 2. Condensers have a cold fluid (usually seawater) in the tubes and steam outside the tubes. The steam condenses as it contacts the cooler tubes. Condensers serve a variety of purposes. Those described in this chapter include main propulsion and turbo-generator turbine exhaust condensers, air ejector condensers, and gland steam condensers. Distilling plants also use condensers. Low-pressure steam distilling plant condensers are described in NSTM Chapter 531, Volume 1, Desalination - Low-Pressure Steam - Distilling Plants. Vapor compression distilling plant vent condensers are described in NSTM Chapter 531, Volume 2.

254-1.1.4 AIR EJECTORS. Unlike heat exchangers and condensers, air ejectors are not heat transfer devices. They are included in this chapter (Section 5) because they are important to the proper functioning of condensers. They use a jet of high-velocity steam to draw air and other noncondensible gases out of condensers, thus maintaining the required vacuum and heat transfer properties. Shipboard air ejectors can be either single stage or multistage units.

## 254-1.2 HEAT TRANSFER

254-1.2.1 GENERAL. A detailed discussion of heat transfer is beyond the scope of this document, but a brief overview may help the reader understand the operating principles of the equipment to be discussed later.

254-1.2.2 HEAT FLOW. Heat exchangers and condensers operate on a fundamental principle of physics: heat will always flow from high-temperature areas to low-temperature areas. During this process the hotter areas will be cooled (as they lose heat) and the cooler areas will be heated.

254-1.2.3 TYPES OF HEAT TRANSFER. There are three types of heat transfer: conduction, convection, and radiation.

254-1.2.3.1 Conduction. In conduction, heat passes directly from one particle to another through a material. Applying heat to a material increases molecular activity. This increased activity stimulates the surrounding molecules, heating them and conducting heat away from the source. Conduction is the only form of heat transfer in solid materials. Liquids and gases can also conduct heat.

254-1.2.3.2 Convection. Convection is the primary form of heat transfer in fluids. In convection, fluid particles are first heated (or cooled) by conduction as they contact a solid surface. As the fluid flows past the surface, heat is transferred away from (or to) the area. In a still fluid, flow will be created by the density changes caused by heating or cooling the fluid. This is called natural convection. Forced convection, where flow is provided by a pump, fan, or other means, gives much higher heat transfer rates. Condensation is a type of convection in which a fluid changes from a vapor to a liquid (it condenses) by contact with cool surfaces. As the vapor condenses, it releases heat (latent heat) without a drop in temperature. In condensers this heat is transferred through the cool surface (the tube wall) by conduction and then into the fluid in the tubes by convection. A variety of fluids are used in naval condensers, but only steam condensers are discussed in this chapter.

254-1.2.3.3 Radiation. Unlike conduction and convection, radiation heat transfer does not need to be transmitted through a medium, or substance. Radiant heat energy travels outward from all objects in the form of electromagnetic waves that, like radio waves or light, can travel through a vacuum. The hotter an object is, the more radiant energy it emits. This energy is converted into heat when the radiation strikes an object. A good example is the heat produced by sunlight. Radiation is not a significant form of heat transfer in any of the equipment discussed in this chapter.

254-1.2.4 HEAT TRANSFER RATE. The types of heat transfer equipment discussed in this chapter have an important similarity. They all transfer heat from one fluid to another through a solid barrier, or wall. This barrier (the tube wall for shell-and-tube heat exchangers, including condensers, and the plate for plate units) directs the flow of the fluids and keeps them from mixing. Both conduction and convection are thus involved.

254-1.2.4.1 The rate of heat transfer in heat exchangers is controlled by three factors: the temperature difference between the fluids, the wall (tube or plate) surface area through which heat can flow, and the overall heat transfer coefficient. The relation is expressed in the equation:

$q = U \times A \times LMTD$ (1.1)

where:

q = heat load (the amount of heat transferred in a given time), usually in British thermal units per hour (Btu/hr)

U = overall heat transfer coefficient in Btu/(hr x °F x $ft^2$ )

A = effective heat transfer surface area in square feet

LMTD = log mean temperature difference, which is the average fluid temperature difference in °F. (The actual difference varies throughout the exchanger since the hot fluid is cooling down and the cold fluid is heating up.) LMTD depends on the initial fluid temperatures and on the flow arrangement.

254-1.2.4.2 In equation 1.1, U accounts for the resistances presented by the various materials and boundaries as heat flows from the hot fluid to the cold fluid. The first of these is the hot fluid resistance to convection (the hot fluid's ability to give up its heat). This depends on the hot fluid's material properties, temperature, velocity, and turbulence. (For condensing, the resistance depends only on the fluid's material properties and temperature.) If the wall surface is clean, the next resistance encountered is the wall's ability to conduct heat through itself. This depends on the wall's material properties, thickness, and temperature. Finally, there is another convective resistance, based on the cold fluid's material properties, temperature, velocity, and turbulence.

254-1.2.4.3 If the wall surfaces are dirty or scaled, one or two more resistances (depending on whether one or both sides are dirty) may be included in U. These are called fouling factors. They are conductive resistances based on the material properties, thickness, and temperature of the fouling. In most heat exchangers, the wall resistance is small compared with the other resistances because most metals used for tube or plate construction are relatively good heat conductors. The convective resistances on both sides of the wall are usually well balanced so that neither impedes heat flow. The scale and fouling that form on heat transfer surfaces, however, are very poor heat conductors. If allowed to build up, their resistances can dominate, effectively limiting the amount of heat the equipment can transfer.

## 254-1.3 COMMON INFORMATION

254-1.3.1 Since condensers are a type of shell and tube heat exchanger, much of the condenser information in this chapter is also applicable to other types of shell and tube units. This is particularly true of maintenance procedures. Section 2 discusses the unique design and operating features of condensers (as compared to other shell and tube units) and their importance to the proper functioning of steam propulsion plants. Where information in Section 3, which discusses shell and tube heat exchangers in general, is identical to the condenser information in Section 2, the text will refer to Section 2.

# SECTION 2.
# CONDENSERS

## 254-2.1 GENERAL

254-2.1.1 SCOPE. This section discusses single pass and two pass main propulsion, turbogenerator, and auxiliary condensers. Air ejector and gland condensers are covered in Section 5.

254-2.1.2 CONDENSER FUNCTIONS. Main propulsion steam systems are designed as closed loops for maximum efficiency. Steam is produced in a boiler or steam generator and fed to the propulsion and auxiliary turbines. It passes through the turbines and is exhausted to the main condenser. The main condenser serves two purposes. It maintains a vacuum to ensure proper steam flow through the system, and it condenses the steam so that it may be pumped back to the boiler to be reused.

254-2.1.3 RELATED MANUALS. Maintaining a proper vacuum is essential for the efficient and safe operation of turbines as explained in detail inNSTM Chapters 231, Propulsion and SSTG Steam Turbines, and 502, Auxiliary Steam Turbines . The necessity for pure boiler feedwater is discussed in NSTM Chapter 220, Volume 2, Boiler Water/Feedwater - Test and Treatment. The feedwater system is described in NSTM Chapter 255, Volume 1, Feed and Condensate Systems. Makeup feedwater is produced in desalination plants. Plant characteristics and operation for low pressure steam and vapor compression distilling plants and for reverse osmosis desalination plants are described inNSTM Chapter 531, Volumes 1, 2, and 3, Desalination.

## 254-2.2 ENGINEERING PRINCIPLES AND EQUIPMENT DESCRIPTION

254-2.2.1 GENERAL Refer to Figure 254-2-1 throughout the following discussion. Steam exhausted from the turbine enters the condenser shell through exhaust opening(s) at the top of the condenser. The steam condenses when it contacts the cold condenser tubes. The condensed steam, or condensate, collects in the space at the bottom of the condenser below the tubes (termed the hot well). The tubes are kept cold by circulating seawater through them to carry away heat given up by the steam in condensing. (This heat is known as the latent heat of vaporization or in connection with condensers, heat of condensation.) The condensate is pumped out of the condenser hot well by condensate pumps, which discharge into the feedwater system. The design rating and details of construction of any particular condenser installation are given in the condenser drawings and equipment manuals on board ship.

254-2.2.2 PRESSURE TEMPERATURE RELATIONSHIPS. A fundamental characteristic of pure water is that when held at a specific pressure and heated, it will boil at a specific temperature. If the pressure is increased, the boiling temperature will also rise. Pure steam at a specific pressure will condense at the same (boiling) temperature if it is cooled. This pressure temperature relationship has been determined experimentally and tabulated. Table 254-2-1 shows this relationship in the normal range of shipboard condenser operation.

254-2.2.2.1 Absolute Pressure Versus Vacuum. Note that for each condensing temperature, the corresponding boiling/condensing pressure is shown in inches of mercury (Hg) absolute and inches of mercury vacuum based on a 30-inch barometer. It is customary to express pressures below atmospheric pressure as a vacuum in inches of mercury below atmospheric pressure.

254-2.2.2.1.1 The mean atmospheric pressure at sea level is nearly 14.7 pounds per square inch absolute (psia), or zero pounds per square inch gage (psig). This corresponds to a mercury barometer column height of nearly 30 inches and a boiling temperature of 212°F. Refinements that account for temperature, elevation, and gravity are necessary for accurate laboratory work, but not for shipboard condenser operation. The data tabulated in Table 254-2-1 are based on standard conditions. The sum of absolute pressure and vacuum therefore equals 30 inches of mercury for any given temperature. True absolute pressure is unaffected by changes in barometric pressure. Any given absolute pressure corresponds to a definite condensing temperature.

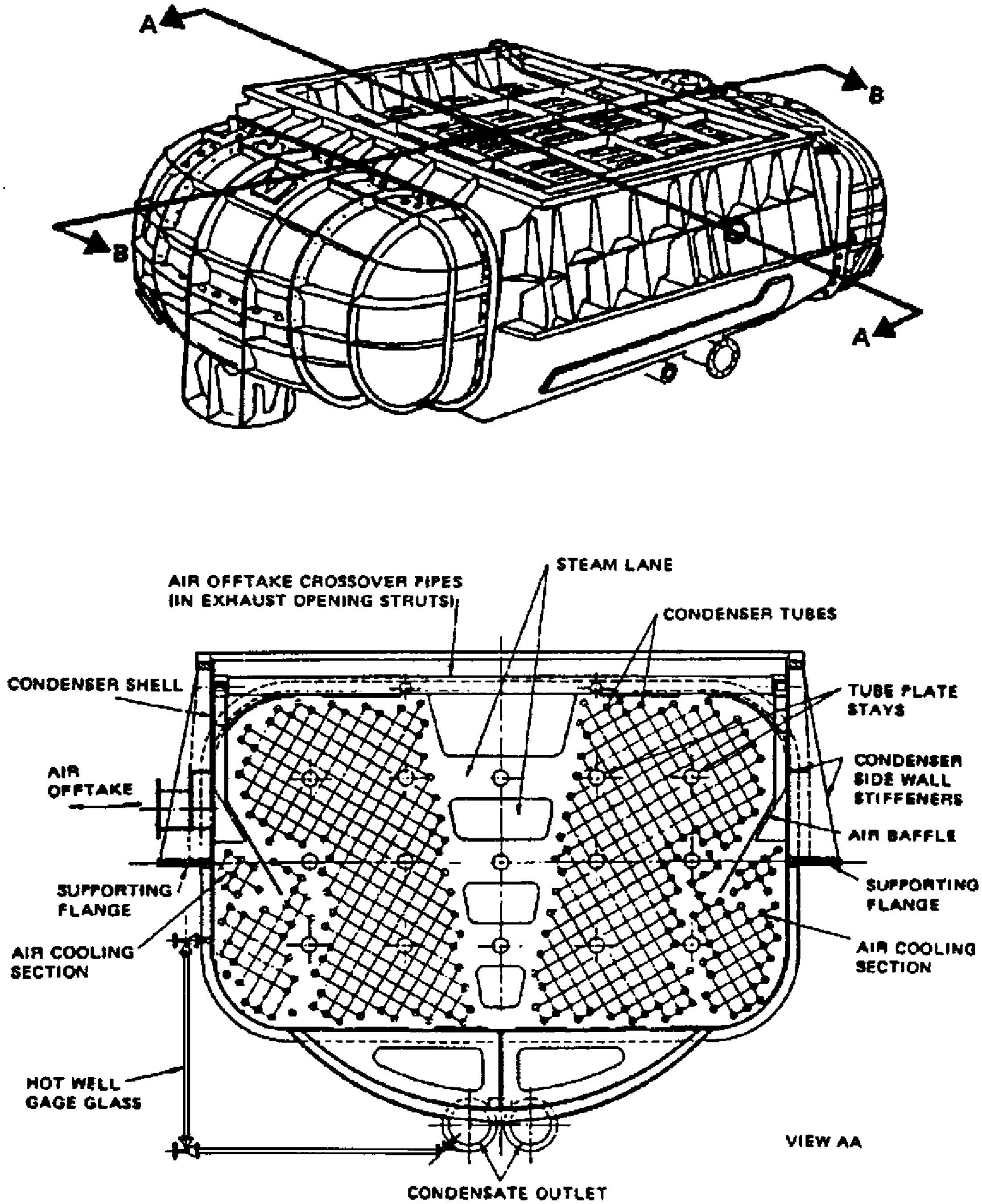



Figure 254-2-1. Typical Main Single-Pass Condenser (Sheet 1 of 2)

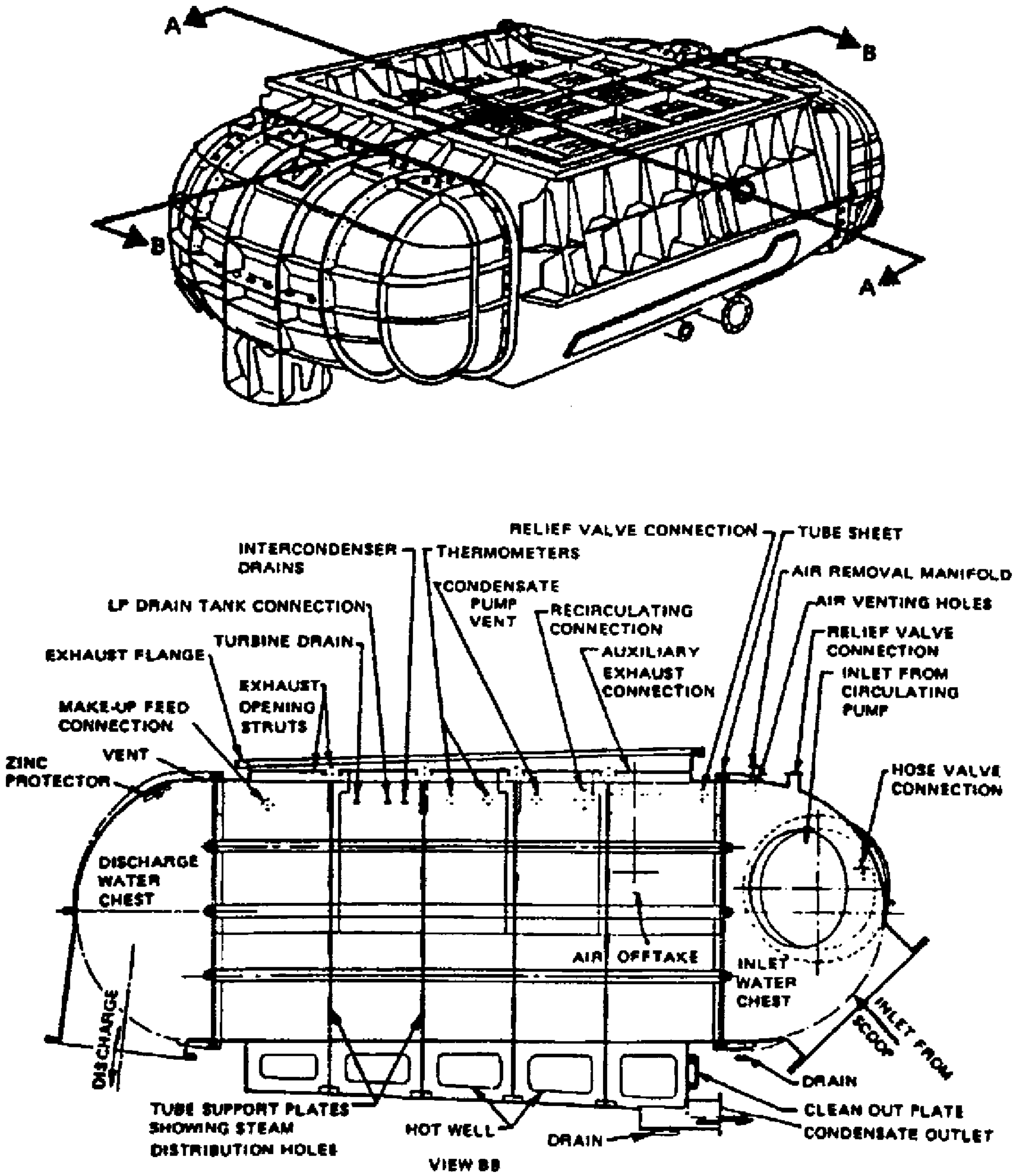



Figure 254-2-1. Typical Main Single-Pass Condenser (Sheet 2 of 2)

254-2.2.2.1.2 Vacuum is normally measured downward from atmospheric pressure as a base. Vacuum gage readings therefore must generally be corrected to standard conditions to determine their corresponding condensing temperature.

254-2.2.2.2 Temperature Difference. Steam in the condenser shell surrounding the tubes tends to condense at a pressure corresponding to the temperature of the tube surface. This is tabulated in Table 254-2-1. In the process of condensing, however, the heat of condensation must be transmitted from the steam to the outside of the tube surface, through the metal wall of the tube, and from the inside of the tube surface to the circulating water flowing through the tubes. Heat can flow in this manner only when the temperature of the steam is higher than the temperature of the circulating water. The rate of heat flow is directly proportional to the difference in temperature between the steam and the circulating water (paragraph 254-1.2.4).

**Table 254-2-1** PRESSURE-TEMPERATURE CONVERSION TABLE

| Absolute Pressure (Inches in Mercury) | Corresponding Vacuum (30-Inch Barometer) | Boiling/Condensing Temperature (°F) |
|---|---|---|
| 0.4 | 29.6 | 52.6 |
| 0.6 | 29.4 | 64.0 |
| 0.8 | 29.2 | 72.3 |
| 1.0 | 29.0 | 79.0 |
| 1.2 | 28.8 | 84.6 |
| 1.4 | 28.6 | 89.5 |
| 1.6 | 28.4 | 93.8 |
| 1.8 | 28.2 | 97.6 |
| 2.0 | 28.0 | 101.1 |
| 2.2 | 27.8 | 104.6 |
| 2.4 | 27.6 | 107.3 |
| 2.6 | 27.4 | 110.1 |
| 2.8 | 27.2 | 112.6 |
| 3.0 | 27.0 | 115.1 |
| 3.5 | 26.5 | 120.6 |
| 4.0 | 26.0 | 125.4 |
| 4.5 | 25.5 | 129.8 |
| 5.0 | 25.0 | 133.8 |
| 5.5 | 24.5 | 137.4 |
| 6.0 | 24.0 | 140.8 |
| 6.5 | 23.5 | 143.9 |
| 7.0 | 23.0 | 146.9 |
| 7.5 | 22.5 | 149.6 |
| 8.0 | 22.0 | 152.2 |
| 8.5 | 21.5 | 154.7 |
| 9.0 | 21.0 | 157.1 |
| 9.5 | 20.5 | 159.3 |
| 10.0 | 20.0 | 161.5 |

254-2.2.2.2.1 When the ship is operated at low cruising power, steam will condense at a pressure corresponding to a temperature only a few degrees higher than that of the circulating water. At full power, when the main condensers are heavily loaded, this temperature difference becomes much greater to enable the heat to flow from the steam to the circulating water rapidly enough to condense the larger quantity of steam.

254-2.2.3 EFFECT OF AIR. If air is allowed to collect in a condenser it insulates the tube surfaces from the steam. This interferes with heat flow and increases the temperature difference between the steam and the circulating water. This causes a corresponding decrease in the obtainable condenser vacuum. Further vacuum reduction is caused by the partial pressure of the air itself, which adds to the steam pressure in the condenser.

254-2.2.3.1 Air Entry. Air enters condensers in various ways. A small amount may be dissolved in the feedwater discharged into the boilers. This air is released with the steam generated and flows into the condenser with the exhaust steam. Air leakage also may occur through improperly sealed turbine glands; through imperfect turbine, condenser, and associated piping joints under vacuum; or through leaky condensate pump or valve glands. When makeup feed and other drains are discharged to the condenser, any air dissolved in these drains tends to system may eventually flow to the condenser, as this is the unit in the system with the lowest absolute pressure.

254-2.2.3.2 Air Removal. If a large air leak develops, condenser vacuum will be immediately and seriously reduced. Take corrective measures at once (paragraph 254-2.6.20). Although constant vigilance is necessary to detect and correct air leaks, a small amount of air will continuously find its way into the condensers during normal operation. Means are provided for continuous removal of this air while the condenser is in use. Air ejectors (Section 5) are used for this purpose in the majority of naval installations, although vacuum pumps are used in some installations. Deaerating feed tanks (DFT) also aid in air removal, as described inNSTM Chapter 255, Volume 2, Deaerating Feed Tanks .

254-2.2.3.2.1 The capacity of air removal equipment is small compared with the amount of steam discharged into the condenser. Condensers are thus arranged so that most of the steam has condensed before the steam-air mixture arrives at the air ejector. (Removing large amounts of steam would also reduce plant efficiency.) To remove air most condensers have air-cooling sections separated from the rest of the condensing surface by air baffles.

254-2.2.3.3 Condenser Air-Cooling and Mounting Arrangements Air-cooling sections are located so that steam entering the condenser must pass over a large number of condensing tubes before it can reach the air-cooling sections. (An example of this arrangement is shown in Figure 254-2-1, view A-A.) Most steam is thus condensed before it reaches the air-cooling sections, leaving this portion of the cooling surface available for cooling only the residual air and other noncondensible gases.

**NOTE**

Always keep air baffles tight and in the proper position to prevent steam from bypassing the air-cooling sections.

254-2.2.3.3.1 Figure 254-2-1 shows a main condenser that supports the main low-pressure turbine. In this case, the turbine is mounted directly on the condenser exhaust flange and the condenser's supporting flanges rest on a foundation built into the ship. The type of air baffle arrangement shown in view A-A of Figure 254-2-1 performs an additional function associated with supporting the turbine. These air baffles are extended up the side of the condenser shell to shield the shell from sudden heating when the astern turbine throttle is opened and astern steam, which in many cases is highly superheated, is discharged into the condenser. This minimizes sudden expansion of the condenser shell, because of temperature changes, to help maintain proper alignment between the turbine shaft and the reduction gear.

254-2.2.3.3.2 In some installations, the condenser hangs from the low pressure turbine so that the turbine supports the condenser. Sway braces connect the lower part of the condenser shell to the ship's structure. The braces must be properly adjusted to prevent undue strain on the turbine casing when the ship is rolling and pitching. Accurately adjusted spring supports are sometimes provided to carry part of the condenser weight and further relieve strain on the low-pressure turbine. Where the condenser hangs from the turbine, only limited expansion and contraction of the condenser shell (caused by exhaust steam temperature changes) can be tolerated. Excessive expansion and contraction will interfere with turbine alinement. In these designs, air cooling sections are frequently located in the central part of the tube layout, with a steam lane between the bundle and condenser shell.

254-2.2.3.3.3 Some main condensers have three air-cooling sections: one in the center and one along each side of the condenser, with steam lanes between adjacent tube banks. To allow for shell expansion due to temperature changes, tube joints may be packed (usually at the outlet end). If the tubes are expanded into the tube sheet at both ends, the condenser shell will have an expansion joint.

254-2.2.4 STEAM FLOW. Steam flows through a condenser from the turbine exhaust inlet toward the air-cooling sections, the lowest pressure region in the condenser. To obtain the highest possible vacuum at the turbine exhaust flange, the condensing surface is arranged for the minimum practical steam pressure drop through the tube bundle.

254-2.2.4.1.1 Tube Spacing. The minimum steam pressure drop is obtained by spacing tubes widely around the edge of the condensing section, where the maximum amount of steam enters the tube bundle (Figure 254-2-1, view A-A). This provides a wide central steam lane for steam to enter the tube bundle. It also means that the steam crosses a relatively short flow path from all parts of the tube bundle periphery (where steam initially enters) to the air-cooling sections.

254-2.2.4.2 Longitudinal Distribution of Steam The wide central steam lane also allows longitudinal distribution of steam (in the direction of the tube axis) in the condenser through large holes in the tube support plates. Longitudinal distribution of steam in the condenser is particularly important in installations where the low-pressure turbine is mounted directly on the condenser and relatively little space is available for steam distribution between the turbine exhaust and the condenser inlet. With double-flow, low-pressure turbines mounted in this manner and with the condenser arranged in the ship with the tube axis fore and aft, most of the exhaust steam discharges into the ends of the condenser. The condenser therefore needs space for steam to flow from the ends to the central portion of the condensing surface. This makes the most effective use of all the surface provided. Longitudinal steam distribution is particularly important during astern operation, especially when there is only one astern element, as on single-flow, low-pressure turbine rotors.

254-2.2.4.3 Circulating Water Temperature Rise. As circulating water flows through the condenser tubes, heat is transmitted from the condensing steam through the tube walls to the circulating water. This gradually raises the temperature of the water as it passes from the inlet to the outlet ends of the tubes. The tube surface near the inlet end is thus colder than that near the outlet end, creating a greater temperature difference between the steam and the tube surface at the inlet end. This end of the condenser is thus capable of condensing more steam than the opposite end. There is a tendency, therefore, for steam to flow longitudinally through the central steam distribution lane to take advantage of the extra condensing capacity near the inlet end of the condenser.

254-2.2.4.4 Condensate Depression. The central steam lane extends completely through the tube bundle, allowing steam to flow directly from the exhaust inlet to the condenser hot well (Figure 254-2-1, view A-A). Steam reaching the hot well through this steam lane (reheating lane) tends to be drawn under the tube bundle towards the sides of the condenser shell and the air cooling section(s), thus sweeping out any air that has collected in the hot well. The condensate dripping from the tubes, having been cooled by contact with the cold tube surfaces, condenses (by direct contact) part of the steam drawn through the hot well. In this way the condensate is reheated to a temperature corresponding to the vacuum maintained in the hot well.

254-2.2.4.4.1 The difference between the temperature of the condensate discharged from the hot well and the temperature corresponding to the vacuum maintained at the turbine exhaust inlet is termed the condensate depression. One criterion of satisfactory design and operation of a condenser is its ability to maintain the condensate depression at a reasonably low value under all normal operating conditions. See paragraph 254-2.2.4.4 for further details.

254-2.2.4.4.2 Excessive condensate depression decreases the operating efficiency of the plant. Subcooled condensate must be reheated by the ship's feedwater heaters, requiring more steam for feed heating than would otherwise be necessary. Excessive condensate depression also permits the condensate to absorb more air. The condenser may then fail to deaerate the drains

254-2.2.5 CIRCULATING WATERFLOW

254-2.2.5.1 Scoop Injection. Continuous circulation of seawater through the condenser tubes at the proper flow rate is essential for all shipboard condenser installations. Seawater is circulated through most combatant ships' main condensers by means of scoop injection (Figure 254-2-2). With the ship underway, seawater entering the scoop has considerable energy due to the relative motion of the water with respect to the ship. This energy is used to force circulating water into the main condenser inlet waterbox, through the condenser tubes, and back to the sea again through the discharge waterbox and the main overboard discharge sea chest.

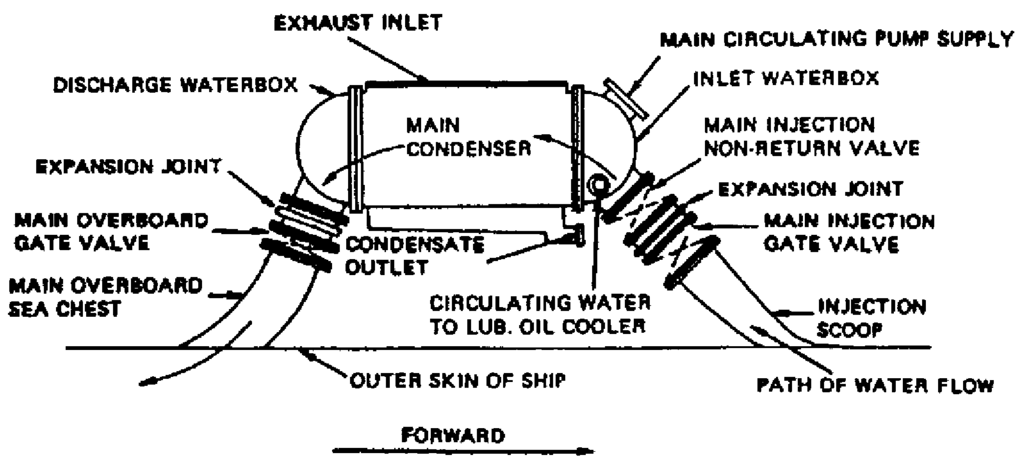



Figure 254-2-2. Scoop-Injected Main Condenser

**CAUTION**

**Make sure that the nonreturn valve does not stick open underway. This would prevent adequate flow of circulating water to the main condenser and cause the pump to run backwards without lubrication, damaging the pump.**

254-2.2.5.2 Main Circulating Pump. A pump circulates cooling water when the ship is on standby, going astern, or maneuvering at slow speeds. This circulating pump usually discharges into the inlet waterbox independently of the scoop discharge. A nonreturn valve, which closes automatically if waterflow reverses, is installed in the scoop discharge piping. Water discharged by the main circulating pump is thus prevented from flowing out through the scoop instead of through the condenser. In some installations the main circulating pump takes suction from the scoop injection piping. Normally, however, a separate suction sea chest, independent of the scoop, is used for more efficient scoop and pump design. This arrangement offers two entirely independent means of circulating seawater through the main condenser in case of derangements. It also permits emergency use of the circulating pump at maximum capacity for pumping bilges, without reducing the flow of circulating water necessary for full-power operation (paragraph 254-2.2.5.3). Gate stop valves are provided adjacent to the scoop, pump suction, and overboard discharge sea chests, for use in case of derangement of the seawater circuit and during condenser upkeep and repair operations requiring draining of seawater from the unit.

254-2.2.5.3 Bilge Suction. Main condenser circulating pumps are provided with a bilge suction connection because they generally constitute the largest available capacity. See paragraph 254-2.4.13 for guidance on obtaining maximum bilge drainage capacity.

254-2.2.5.4 Rubber Expansion Joints. In current ship designs, the rubber expansion joint in the main injection piping from the scoop is between the sea valve and the nonreturn valve. This prevents loss of main circulating pump water in the event of major damage to the rubber expansion joint. (Maintenance of rubber expansion joints is covered inNSTM Chapter 505, Piping Systems .)

## 254-2.3 CONDENSER TYPES

254-2.3.1 SINGLE-PASS CONDENSERS. All scoop-injected main condensers aboard surface ships are single-pass; circulating water flows through all condenser tubes in the same direction. The capacity of the main circulating pump for these condensers may be smaller than that required for full-power operation because maneuvering and astern operations of the ship do not require full circulating waterflow. The main condenser used on a typical combatant is shown in Figure 254-2-1. View A-A is a cross-sectional view, and view B-B is a longitudinal view. The function of the scoop-injected, single-pass condenser is discussed in paragraphs 254-2.2.5.1 and 254-2.4.1.1.

254-2.3.2 TWO-PASS CONDENSERS. Ship's service turbine generator and auxiliary steam condensers must be able to handle full-connected exhaust steam load whether the ship is underway, at anchor, or at full power. These condensers therefore have circulating pumps instead of scoop injection so that water circulation is independent of the ship's motion. To reduce the quantity of water that must be pumped, these condensers generally have two passes. The circulating water is pumped through about half of the tubes in one direction and returned through the rest of the tubes in the opposite direction. A division plate is provided in the inlet discharge waterbox to direct the incoming water through the lower half of the tube bundle. The return waterbox directs the water discharged from the first-pass tubes and conveys it to the second-pass tubes. A schematic of a two-pass condenser is shown in Figure 254-2-3. The arrows show waterflow.

254-2.3.3 COMPARISON OF SINGLE-PASS AND TWO-PASS OPERATION. For a given velocity of circulating water, a single-pass condenser will circulate twice as much seawater as a two-pass condenser of the same general proportion and size (Figure 254-2-4). The circulating water in the two-pass condenser is in thermal contact with the condensing steam (through the tube wall) for twice as long a path, and is thus heated to a higher temperature than under similar conditions in a single-pass condenser. The average tube surface temperature of the two-pass condenser is thus higher than that of the single-pass condenser. For equal size units under similar conditions of steam loading and circulating water velocity, a lower vacuum is therefore obtainable with single-pass condensers. For this reason, the usual naval practice is to use a single-pass condenser where large quantities of water can be circulated efficiently by a scoop. Where circulating pumps are needed to condense full connected steam at low ship speeds, two-pass condensers are generally used to reduce the amount of water that must be pumped.

## 254-2.4 OPERATING PRINCIPLES

254-2.4.1 VACUUM REGULATION. When warming up, standing by, getting underway, cooling down, and securing turbines and engines, regulate condenser vacuum according to the instructions in NSTM Chapters 231 and 502. In emergencies, if it is necessary to obtain the greatest possible power from a turbine regardless of economy, maintain the condenser vacuum as high as possible.

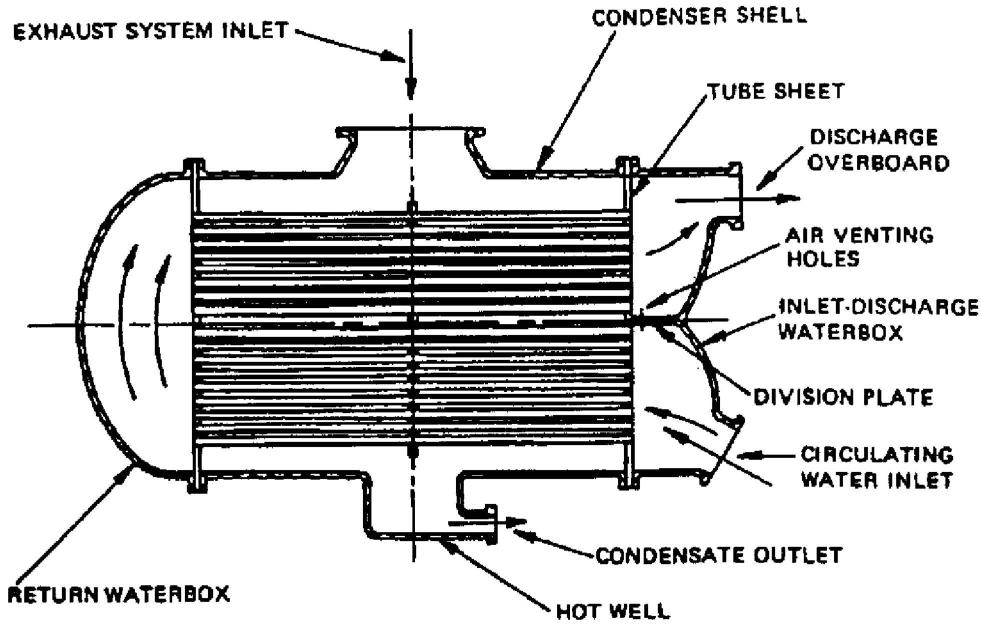



Figure 254-2-3. Two-Pass Condenser Schematic

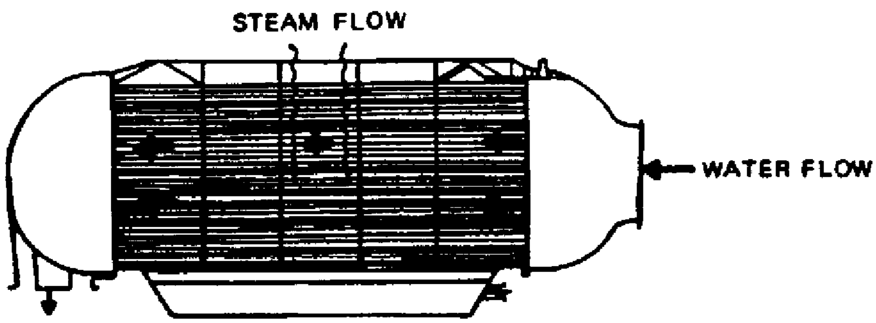



Figure 254-2-4. Single-Pass Condenser Circulation

254-2.4.1.1 Scoop-Injected Condensers. During normal operation, maintain the maximum vacuum obtainable on condensers fitted for scoop injection, with main injection and overboard valves wide open. Certain conditions, however, require modification of this procedure, as described in the following paragraphs.

254-2.4.1.1.1 When making full (or nearly full) power under conditions of cold injection temperature, the condenser will usually be capable of maintaining a vacuum higher than that which can effectively be used by the turbine. The higher the vacuum, the lower the condensate temperature will be. As the full-power vacuum approaches 1 inch of mercury higher than that for which the turbine was designed, the extra steam required by the feedwater heaters (to heat the condensate sufficiently) tends to outweigh the added economy of turbine operation at the higher vacuum.

254-2.4.1.1.2 The design full-power vacuum for any particular turbine installation may be determined from the machinery specifications for the plant. Before 1950, most turbines served by scoop-injected condensers were designed for a full-power exhaust vacuum of about 27-1/2 inches of mercury with a circulating water injection temperature of 75° F. If the injection temperature drops so low that the full-power vacuum rises above 28-1/2 inches of mercury, overall plant economy can be improved by throttling the flow of circulating water to limit the vacuum to 28-1/2 inches of mercury (paragraph 254-2.4.6). In later ships, turbines served by scoop-injected condensers were designed for a full-power exhaust vacuum of 25 inches of mercury with a circulating water injection temperature of 75° F. This lower vacuum offered the advantages of decreased size, space, and weight requirements for the main condensers. In this case, circulating water should be throttled as required to limit the vacuum to approximately 26 inches of mercury.

254-2.4.1.1.3 When operating at cruising speeds, turbines generally can make effective use of the maximum vacuum that the condensing plant can produce. At low power and with cold injection temperature, however, the condenser becomes capable of producing a vacuum higher than the air removal equipment can handle. (A higher vacuum means a higher rate of air leakage into the system.) Under standby conditions, with little steam discharged to the condenser, most installations with properly functioning air ejectors will produce a maximum vacuum of about 29-1/2 inches of mercury with cold injection temperature.

254-2.4.1.1.4 When operating at low and medium power with cold injection temperature, the condenser vacuum will increase to the point where the air ejectors will be unable to remove normal air leakage. Air will collect in the condenser, insulate the tubes from the condensing steam, and settle into the hot well. Usually, a noticeable increase in the condensate depression will occur. To avoid a loss of economy and absorption of air into the condensate under these conditions, throttle the flow of circulating water to limit the vacuum to about 0.2 inch of mercury less than the maximum obtainable with full flow of circulating water, or as necessary to reduce the condensate depression to normal (paragraph 254-2.4.6). If the condensate depression remains between zero and about 2 degrees under low-power operation at medium injection temperature, it may be assumed that air removal equipment is adequately removing excess air. Throttling the circulating waterflow is therefore unnecessary.

254-2.4.1.2 Pump-Circulated Condensers. Under most normal operating conditions, the flow of circulating water in scoop-circulated condensers is automatically controlled to approximately the correct amount by the ship’s speed. With pump-circulated condensers no such automatic flow control is provided. Operating personnel must therefore take greater care to ensure proper water circulation. Circulating waterflow through condensers served by turbine-driven pumps and variable-speed direct current motors is controlled by pump speed regulation. Where constant-speed, alternating current, motor-driven circulating pumps are used, regulate flow by throttling the stop valve in the circulating water overboard discharge piping (paragraph 254-2.4.6.2). If a multispeed, alternating current motor drive is used, regulate flow by motor speed control and throttling, as required by operating conditions.

254-2.4.1.2.1 When operating at or near full power with cold injection, regulate waterflow, if necessary, to avoid producing a vacuum greater than 29 inches of mercury for turbines designed for 28 inches of mercury full power vacuum. Also limit vacuum to 29.3 inches of mercury for turbines designed for 28-1/2 inches of mercury vacuum, and to 27 inches of mercury for turbines designed for 25 inches of mercury vacuum. When operating at low or medium power, regulate circulating waterflow, as necessary, to avoid condenser vacuums for which air removal equipment is inadequate and condensate depression becomes too high.

254-2.4.1.2.2 Do not continuously operate lightly loaded, pump-circulated condensers with the maximum quantity of circulating water, if any safe means of regulating the waterflow is available. Such operation causes condenser tube deterioration, increased condensate depression, and increased pumping costs.

**CAUTION**

**A loss of vacuum accompanied by a hot or flooded condenser can degrade condenser performance and damage the turbine. If vacuum loss occurs, slow down or stop the units exhausting into the condenser until the problem is found and corrected.**

254-2.4.2 INADEQUATE VACUUM. Combatant ship main condensers are much larger than required for normal cruising speeds since they are designed to maintain adequate vacuum under the increased steam load conditions of full-power operation. For this reason condenser operation and maintenance conditions that will prevent adequate full-power vacuum may not be noticed under the lightly loaded conditions of normal operation at cruising speeds because the vacuum appears adequate under these conditions. The dangerous results of machinery plant operation at inadequate vacuum are generally much more pronounced and rapid during operation at high power than at low power. It is therefore important to measure the vacuum periodically even if no problems are observed during normal operation. Make sure that vacuum measurement devices are accurate and that gage and thermometer observations are properly interpreted.

254-2.4.2.1 Causes. The most common causes of inadequate condenser vacuum are:

a. Excessive air leakage into the vacuum system.

b. Improperly functioning air removal equipment.

c. Improper drainage of condensate from condenser.

d. Insufficient flow of circulating water.

e. High injection temperature.

f. Dirty condenser.

254-2.4.2.2 Measuring by Vacuum Gage. The actual pressure and temperature conditions maintained in a condenser are basically independent of the atmospheric pressure. Ordinary dial type (Bourdon) vacuum gages do not measure actual (absolute) condenser pressure but rather the difference between the internal pressure in the gage element and the barometric (atmospheric) pressure. Readings of this pressure difference will be incorrect unless the gage is properly adjusted (see NSTM Chapter 504, Pressure, Temperature, and Other Mechanical and Electromechanical Measuring Instruments ) and the line connecting the gage to the condenser is airtight and free of condensate. If the vacuum gage reading remains nearly constant for several minutes with the stop valve at the condenser end of the gage line tightly closed, the line is airtight.

254-2.4.2.2.1 To ensure the quick and accurate response of vacuum gages to all possible condenser vacuum transients, vacuum gage lines should have a 1/2-inch outside diameter tubing and be as short as possible. They should be free of loops or other trap devices and should have a continuous upward slope of at least 1 inch per foot from the condenser to the gage.

254-2.4.2.2.2 Keep vacuum gage line stop valves and cocks wide open to minimize the effect of minor air leakage on the gage readings. If any section of the gage line is at a lower temperature than the temperature corresponding to the absolute pressure in the condenser, condensate may form in the line and gage readings may be inaccurate. If the gage is properly adjusted and there are no air leaks or condensate in the gage line, the gage reading subtracted from the true atmospheric pressure (as determined from an accurate barometer located near the gage) will equal the absolute pressure in the condenser. If this absolute pressure in inches of mercury is subtracted from 30, the result will be the vacuum corrected to standard conditions (corresponding to a 30-inch barometer reading), as given in Table 254-2-1. Changes in atmospheric pressure thus have a direct effect on the readings obtained from a dial-type vacuum gage. This must be accounted for when judging the performance and operation of condensers. One of the most important and reliable functions of the dial-type vacuum gage is to indicate rapid or unusual changes in vacuum that require immediate corrective measures.

254-2.4.2.3 Measuring by Absolute Pressure Gage. The main condenser installation on some older surface ships includes an absolute pressure gage that consists of a vertically mounted glass tube with its lower end submerged in a closed mercury cistern. The top of the glass tube is sealed and the base of the tube is completely filled with mercury. The top of the closed cistern is connected to the condenser exhaust trunk by a gage line. A catch chamber fitted with a glass port is usually provided in the connecting line adjacent to the gage to catch any mercury spilling out of the cistern or any condensate from the gage line. The manufacturer's instructions provide details of the construction, adjustment, and repair of these instruments. Since the mercury in the absolute pressure gage is not exposed to the atmosphere, the absolute vacuum or pressure indications are unaffected by changes in atmospheric pressure and no correction needs to be made. If the absolute pressure gage is properly adjusted and there are no air leaks or condensate in the gage line or any part of the instrument, the absolute pressure readings obtained should correspond closely with the dial-type vacuum gage readings properly corrected to standard conditions. Make sure that the gage line connection to the absolute pressure gage is such that mercury spilling out of the gage will be trapped in the catch chamber or other device and cannot enter the condenser. If mercury enters the condenser through the gage line, it can cause condenser tube failure through stress corrosion cracking.

254-2.4.2.4 Measuring by Exhaust Trunk Temperature. The temperature of the steam entering a condenser generally provides a good indication of condenser vacuum if the steam is not superheated and the thermometer is accurate and properly located. The steam exhausted from main propulsion turbines is not normally superheated under ahead operating conditions but it may be highly superheated when running astern. For this reason two thermometers are usually installed in the condenser exhaust trunk; one measures the normal (ahead) steam temperature range and the other, the maximum temperature range (running astern at full power and carrying full superheat).

254-2.4.2.4.1 The normal range thermometer can be easily tested for accuracy aboard ship (see NSTM Chapter 504) and, unless actually broken, can be accurate over long periods of time. Because no barometer correction is required, the temperature readings can be directly converted to condenser exhaust trunk absolute pressure values using Table 254-2-1. While the data obtained are theoretically subject to several corrections (stem length, ambient temperature, air leakage, and steam velocity), none are required for shipboard purposes. An accurate condenser exhaust trunk thermometer will provide a good measurement of the condenser vacuum when the turbine exhausting to the condenser is operating steadily ahead at medium or full power.

254-2.4.2.4.2 The thermometer should be located in the condenser exhaust trunk rather than in the turbine exhaust trunk. Make sure that the thermometer is not located in an area of the condenser shell heated or cooled by adjacent pipes. The thermometer and thermometer well should also not be near hot or cold drains in or external to the condenser or near the auxiliary exhaust inlet to the condenser (unless observations are made when the back-pressure valve is secured). The thermometer well must be exposed to the direct flow of exhaust steam before it reaches the tube bundle but it also must be located several inches away from the nearest tubes.

254-2.4.3 AIR LEAKAGE. Excessive air leaking into a condenser decreases the obtainable vacuum and increases condensate depression and aeration. Constant attention is required to detect and eliminate air leaks into the vacuum system. (See paragraph 254-2.6.20 for air leak test methods.)

254-2.4.3.1 The most likely cause of a rapid decrease in vacuum under steady operating conditions, or an unexpected decrease in vacuum under maneuvering conditions, is a large air leak into the vacuum system. (See paragraph 254-2.4.2.1 for other common causes). The failure of a condenser to produce a vacuum under standby conditions as high as is normally obtainable with the same injection temperature generally indicates excessive air leakage into the vacuum system or improperly functioning air removal equipment.

254-2.4.4 CONDENSATE DEPRESSION. An abnormally high condensate depression under steady operating conditions indicates excessive air leakage, improper condensate removal (paragraph 254-2.4.5), excessive circulating waterflow, or improperly functioning air removal equipment. Condensate depression normally increases when makeup feed is admitted into the condenser. With the makeup feed line secured, most naval condensers designed for internal steam distribution (through steam reheating lanes or other means) should maintain a condensate depression of 0 to 2 degrees when properly operated at low or medium power.

254-2.4.4.1 In some installations (particularly those without reheating lanes or with closely spaced tubes throughout the tube bundle) higher condensate depressions are normal. In addition, high apparent condensate depression is normal during high-power operation, particularly with a cold injection temperature. This is caused by overloading the steam passages to the hot well. The result is an increase in the pressure drop of the steam crossing the condensing surface and a vacuum in the hot well greater than that in the condenser exhaust trunk. The condensate is thus cooled to a temperature corresponding to a higher vacuum than that maintained in the exhaust trunk. There is also an apparent increase in condensate depression.

254-2.4.4.2 Accurately determining condensate depression and knowing the normal condensate depression for a particular condenser under various operating conditions are necessary to determine whether the condenser is operating properly. Since the temperature differences are usually small, the thermometers in the condensate line must be in good condition and the exhaust trunk temperatures or vacuum must be measured accurately.

254-2.4.5 CONDENSATE DRAINAGE. A hot well gage glass is provided (Figure 254-2-1, view A-A) for observing the condensate level in the condenser. High condensate levels can degrade condenser performance and even cause turbine casualties. If the condensate level rises in the hot well its first effect is to restrict the flow area for reheating steam and, thus, increase the condensate depression (paragraph 254-2.4.4). As the condensate level rises higher and contacts the lower tubes in the condenser, condensate temperature decreases further. If the condensate level rises high enough to cover the lower edges of the air baffles, air removal ceases. This, combined with the reduction in condensing surface, results in a large and rapid decrease in vacuum. Take immediate corrective action to reduce condensate levels and thus prevent a major casualty. Improper draining of condensate from a condenser results from malfunctioning (or improperly operated) condensate pumps. Further instructions can be found in NSTM Chapter 503, Pumps.

254-2.4.6 CIRCULATING WATER REGULATION. Follow the instructions below to regulate the flow of circulating water through the condensers.

254-2.4.6.1 General.

a. Do not regulate waterflow by throttling valves in the water supply piping unless the valves are at least seven pipe diameters away from the entrance to the waterbox. In most cases this requirement eliminates using condenser injection piping valves for throttling, but in some small heat exchangers the inlet valve may be located at a sufficient distance from the unit. If the throttled valve is too close to the condenser or heat exchanger, the added turbulence in the circulating water can accelerate the deterioration of the condenser tubes and tube sheets (paragraph 254-2.6.15).

b. Do not regulate waterflow by throttling valves in the overboard discharge piping of condensers or heat exchangers served by positive-displacement circulating pumps.

c. Fill all tubes completely with circulating water (paragraph 254-2.6.15.3).

254-2.4.6.2 Surface Ships. When throttling gate valves in the circulating water discharge piping to regulate waterflow, keep the valves at least 1/4 open. If a gate valve used for throttling is more than 3/4 closed, the disk may pound against the valve seat, damaging the valve so that it will not be watertight when closed. When overboard gate valves are continually used for throttling, the valve disk and seating surfaces may become slightly eroded. Inspect the seating surfaces of these valves whenever the ship is drydocked. If a sudden increase in power is required when an overboard valve is used for throttling, some further opening of the valve may be necessary. Any temporary loss in vacuum before readjustment has been made is usually not large or serious. If an unexpected demand for full-power astern occurs, fully open the overboard valve as quickly as possible.

254-2.4.6.2.1 Surface ship condenser waterboxes normally should not be subjected to a pressure greater than the waterbox relief valve setting. A relief valve is provided on the inlet waterbox of every condenser. On ships built before 1950 this valve is set at 15 psi and, for later ships, at 20 psi. The pressure setting may be higher on deep draft ships such as aircraft carriers. Consult the applicable condenser technical manual. For main condensers this relief valve shall be at least 2 inches nominal pipe size and for other condensers at least 1 inch.

254-2.4.6.2.2 Do not rely on the waterbox relief valve to protect the condenser waterside from excessive pressures during operation. It will, however, serve as a sentinel valve if excessive pressures are encountered. The main purpose of the relief valve is to protect the condenser watersides from excessive pressure due to the expansion of the water as it warms to engine room temperature. Excessive pressure will only occur if the watersides are secured full of cold seawater while the injection, overboard, and vent valves are tightly closed. Examine waterbox relief valves and lift by hand whenever the condensers are secured. Test with water pressure after any major condenser repairs or if there is any question about their setting.

254-2.4.7 INSUFFICIENT CIRCULATING WATERFLOW. Regulating circulating waterflow when an ample supply of water is available is discussed in paragraph 254-2.4.6. Always provide an adequate flow of circulating water when condensers are operating. If sufficient circulating water is unavailable it will be impossible to maintain the required vacuum. Reduced flow can also lead to overheating failures such as leaky tube joints or bowed tubes and tube sheets. To prevent overheating, do not allow the circulating water outlet temperature to exceed 140 degrees F. The most common cause of insufficient circulating waterflow is improper operation or failure of the circulating pumps. NSTM Chapter 503 provides instructions on operating and maintaining circulating pumps. The following paragraphs describe other common causes of inadequate circulating water flow.

254-2.4.7.1 Injection and overboard discharge sea chests, strainers, piping, or valves may be obstructed by foreign matter, by insufficiently opened valves, or by a valve disk becoming detached from its stem. Steam or air connections are provided to clear foreign matter from sea chests. (The procedure, precautions, and allowed pressure can be found in NSTM Chapter 505). Sometimes thick growths of grass rooted on or around the openings of sea valves cannot be permanently blown clear because suction draws them back into the strainer openings. In such cases and also when the maximum allowed pressure fails to clear a strainer, the obstruction must be removed by long-handled wire brushes or by a diver.

254-2.4.7.2 Foreign matter can clog condenser tubes and degrade condenser tube service life and reliability. Clogging that seriously interferes with circulating waterflow or vacuum, however, is unusual.

254-2.4.7.3 If large quantities of air are allowed to collect in the upper part of the waterboxes, part of the cooling surface will be removed from service and circulating waterflow reduced. In some cases sufficient air will collect to reduce the vacuum. If only a few tubes are affected, there will be no noticeable effect on the vacuum, but dry tubes will overheat and expand. This is particularly true of main condensers running astern and subjected to turbine exhaust steam temperatures over 450°F. This overheating and expansion may warp tubes, loosen expanded tube joints, and cause warped tubes to withdraw into the packing glands of packed end tube joints. Any of these problems can cause salt water to leak into the condensate. Lightly reroll leaking, expanded tube joints. Plug warped tubes in which the outlet ends have withdrawn into the packing gland such that the tube ends are below the outer ring of packing (paragraph 254-2.6.27).

254-2.4.7.4 Air vents are provided at the top of all condenser and heat exchanger waterboxes. Provide sufficient cooling waterflow and pressure so that water flows continuously from these vents under all operating conditions. Where these vents on main condensers are piped overboard through the hull or where inlet waterbox vents are piped to the discharge waterbox or piping, keep the vent valves wide open under all operating conditions to minimize air erosion of tubes (paragraph 254-2.6.15.3) and avoid air binding of the condenser. Where these air vents are piped to the bilge or other shipboard spaces, keep them slightly open at all times when the condenser or heat exchanger is in use. As long as a trickle of water escapes the unit cannot become air bound.

254-2.4.7.5 If the division plate of a two-pass condenser is dislodged or displaced by the circulating water, the water will bypass the tubes and affect the condenser vacuum. If the gasket between the division plate and the tube sheet is dislodged, the leakage will generally be insufficient to reduce the vacuum. It will, however, seriously erode the tube sheet and adjacent tubes (paragraph 254-2.6.15.5).

254-2.4.7.6 Insufficient flow through scoop-injected condensers can also result from failure to start the main circulating pump when the ship is maneuvering, stopping, or going astern.

254-2.4.7.7 Nonreturn valves in the scoop injection or main circulating pump discharge piping may fail to open fully or to close with a reversal of flow. This normally indicates that the valve disk shaft bearings of the stuffing box glands have been set too tightly. If the main circulating pump nonreturn valve fails to close properly and permits enough backflow through the pump to make it run in reverse, a serious pump casualty could be caused by the failure of the pump lubrication system.

254-2.4.7.8 If the ship has been grounded, distortion of the injection or overboard sea chest strainer bars, plates, or projecting lips may restrict the normal flow of circulating water. Repairs usually require drydocking. Whenever the ship is drydocked, these parts should be carefully cleaned, examined for damage, and brought into agreement with the ship's plans in all details (NSTM Chapter 505).

254-2.4.7.9 If it is necessary to operate a condenser with a disabled circulating pump, circulating water sufficient for operating at reduced power and vacuum can usually be supplied by using regularly-installed cross-connecting lines or a temporary hose connection from the fire or flushing main to the condenser inlet waterbox. Make no permanent connection between the condenser and a fire main, flushing main, or any other water supply system that could subject the condenser to pressures greater than 15 psig if the condenser was secured with an inoperative waterbox relief valve.

254-2.4.7.10 In an emergency, scoop-injected condensers can be operated, after getting underway, with the main circulating pumps disabled. For single-screw ships, circulating water sufficient for getting underway can generally be provided by auxiliary means (paragraph 254-2.4.7.9). Multiple shaft ships can get underway with a secured disabled circulating pump on one of the propelling units. When underway at a speed of 5 to 6 knots, the scoop will generally provide enough circulating water to warm up and start the idle propelling unit. Operation at all higher speeds ahead, up to and including full power, is then independent of the main circulating pumps. Take care, however, to avoid damage when the ship's speed is reduced below that required for operating the scoop system or when other propelling units are run astern. When at maximum speed on multiple shaft ships with scoop injection and one or more shafts disabled, it may be necessary to run the main circulating pumps for the shafts operating at maximum to augment the flow produced by the scoops and achieve maximum vacuum.

**CAUTION**

**Resuming normal circulating waterflow (either with the circulating pump or by increasing the ship's speed) through a hot condenser in which steam has formed on the seawater side may cause severe water hammer from steam collapse, damaging the condenser and circulating water piping, and possibly rupturing the expansion joints and flooding the associated engineering spaces.**

254-2.4.8 CIRCULATING WATER LOSS (SCOOP-INJECTED CONDENSERS). Circulating water loss (from improper operation or failure of circulating pumps) in an operating condenser will result in overheating and steam formation on the seawater side of the condenser. The following paragraphs describe the causes and effects of hot condensers and casualty procedures for scoop-injected condensers on surface ships.

254-2.4.8.1 Steaming a Condenser with No Seawater Flow and the Seawater Valves Open. If seawater flow stops and the injection and overboard valves are open, steam exhausted from the turbines will boil the seawater and form steam in the waterboxes and tubes. This creates the danger of water hammer if flow is suddenly resumed. If seawater flow is suddenly lost, take immediate steps to secure all steam entering the condenser. If all steam cannot be secured and if seawater flow cannot be reestablished immediately, secure either the two main seawater inlet valves or the overboard discharge valve at once. Fully open the vent and drain valves on the waterbox at the end of the condenser where the main seawater valves are secured to establish natural circulation.

**NOTE**

Each ship shall predetermine the valve lineup that provides the greatest natural cooling flow through the condenser tubes. The objective is to decrease condenser temperature slowly by venting hot water or steam (if formed on the seawater side) without causing turbulent mixing while the circulating water temperature is above 140°F or other temperature as specified in the applicable steam plant manual. Unless otherwise directed by the steam plant manual or Engineering Operating Sequence System (EOSS), include this valve lineup in an Emergency Cooling Procedure for Hot Condensers and post it in an appropriate location.

254-2.4.8.1.1 Continue urgent efforts to stop the flow of steam and drains to the condenser. This includes closing the valves on the auxiliary exhaust dumping line to the condenser, the condensate recirculation lines from the deaerating feed tank (DFT), the vacuum drag line from the freshwater drain tank, and the catapult drain line (where installed). Maintain seawater flow by natural circulation through the waterbox vent and drain until the temperature of the circulating water in the waterbox is below 140°F or other temperature as specified in the applicable steam plant manual. Do not attempt to resume normal circulating waterflow until this temperature has been reached.

254-2.4.8.2 Steaming a Condenser with No Seawater Flow and the Seawater Valves Closed. With no seawater flow and the seawater valves closed, shell and seawater side overpressure can occur. This may result in bulging of condenser waterboxes and shell if the relief valves fail to open, causing leakage at the distorted joints. When the seawater valves are closed, make sure that steam is not exhausted to the condenser. If the condenser is to be put into service, follow the established starting and operating procedures before admitting exhaust steam. Establishing coolant flow to a condenser or cooler before admitting hot fluid is always good operating procedure and a preliminary step in the standard starting and operating procedure.

254-2.4.8.2.1 If steam is being exhausted to the condenser with the sea valves closed and the waterside filled, immediately stop all steamflow to the condenser. Open the waterbox vents to permit any steam buildup from boiled circulating water to escape. Slowly open the injection sea valve and then the waterbox drain valves to establish circulation for slow cooldown. Continue condenser cooldown with flow through the vents and drains until the waterbox temperature drops below 140°F or other temperature as specified in the applicable steam plant manual before initiating normal circulating waterflow.

254-2.4.8.3 Steaming a Condenser with the Seawater Side Drained. With no cooling water in the condenser, steam exhausted to the condenser will result in overheating, causing the tubes to bow and tube joints to loosen. When the seawater side is drained, take steps to ensure that steam will not be exhausted to the condenser. When the condenser is to be restored to service, follow the established starting and operating procedures before admitting steam.

254-2.4.8.3.1 If steam is being exhausted to the condenser with the waterside drained, immediately stop all steamflow to the condenser and allow the condenser to cool down slowly to avoid excessive thermal distortion. When it has cooled sufficiently, inspect the condenser for physical damage, particularly the tube sheets, tubes, and tube joints. Perform a seawater side hydrostatic test before operating the condenser. If the condenser is not damaged, place it into operation in accordance with established starting and operating procedures before admitting steam.

254-2.4.9 HIGH INJECTION TEMPERATURE. The temperature of the circulating water directly influences the maximum vacuum a condenser can maintain. For small changes in the injection temperature at constant power, the exhaust steam temperature corresponding to the vacuum will vary by roughly the same amount as the variation in injection temperature (if air leakage is not excessive).

254-2.4.9.1 There is no simple rule for predicting the effect of injection temperature variations on condenser vacuum. A number of variables are involved, including the flow, viscosity, and conductivity of water with temperature changes; steam pressure drop; vacuum changes; and steamside tube surface cleanliness. Under full-power operation, however, the procedure in the following paragraphs will provide for approximate comparisons between high injection temperature and design performance. Consult condenser drawings for the design full-power condenser vacuum rating and the injection temperature on which the vacuum rating is based.

254-2.4.9.2 If the actual injection temperature is higher than the design injection temperature, calculate the approximate full-power vacuum as follows:

$$EV = DV + d\left(1-\frac{d}{100}\right)$$

where:

EV = Temperature (degrees F) corresponding to full power vacuum with high injection temperature.

DV = Temperature (degrees F) corresponding to design full power vacuum at design injection temperature.

d = The difference (degrees F) between design injection temperature and the actual (higher) injection temperature during the full-power run.

Example: A ship whose main condenser drawings specify a design full-power vacuum of 27-1/2 inches of mercury (corresponding to a condensing temperature of about 108.7°F (Table 254-2-1)) with 75°F injection temperature makes a full-power run with 86°F injection:

$$EV = DV + d\left(1-\frac{d}{100}\right)$$

where:

$$\begin{aligned} EV &= 108.7\text{–}(86\text{–}75)\ x\ \left(1-\frac{86-75}{100}\right) \\ &= 108.7\text{–}11\ x\ \left(1-\frac{11}{100}\right) \\ &= 108.7 + 11(0.89) \\ &= 108.7 + 9.79 \\ &= 118.5°\ F \end{aligned}$$

This corresponds to a vacuum of approximately 26-1/2 inches of mercury (Table 254-2-1). This means that during the full-power run with 86°F injection and a properly operated and maintained condensing plant, a vacuum of about 26-1/2 inches of mercury should be maintained in the main condensers.

254-2.4.10 LOW INJECTION TEMPERATURE. If the actual injection temperature is lower than the design injection temperature, the approximate full power vacuum may be calculated as follows:

$$EV = D - d\left(1-\frac{d}{100}\right)$$

Example: In the example cited in paragraph 254-2.4.9.2, if the injection temperature is 49°F, instead of 86 degrees F,

$$EV = 108.7 - (75 - 49)\ x\ \left(1 - \frac{75 - 49}{100}\right)$$
$$= 108.7 - 26\ x\ \left(1 - \frac{26}{100}\right)$$
$$= 108.7 - 26(0.74)$$
$$= 108.7 - 19.2$$
$$= 89.5^{\circ}\ F$$

This corresponds to a vacuum of 28.6 inches of mercury. That is, during the full-power run with 49°F injection and a properly operated and maintained plant, a vacuum of about 28.6 inches of mercury should be maintained.

254-2.4.11 OPERATION IN PORT. Do not use the ship main condensers unless absolutely necessary in polluted water because this can lead to tube deterioration. Operating auxiliary turbogenerator condensers in port is generally necessary unless power from external sources is available. To minimize damage to these units, however, when more than one auxiliary condenser is available, shift the load from one unit to another, following the appropriate procedures, and flush out and clean the idle auxiliary turbogenerator condensers.

254-2.4.12 IDLE CONDENSERS. The following paragraphs describe the lay-up requirements for the steam and seawater sides of condensers.

254-2.4.12.1 Steamside Lay-up and Drying. Lay-up requirements for the steamsides of condensers are divided into the following categories:

a. Idle periods less than 2 weeks

b. Idle periods from 2 to 5 weeks

c. Extended idle periods over 5 weeks

254-2.4.12.1.1 When the condenser is not operating, lay up the steamside of the condenser as follows:

a. For planned idle periods less than 2 weeks, the condensers need not be drained, but the hotwell level should be maintained in the indicating range on the hotwell gage glass. However, to minimize the generation of corrosion products, it is preferred that the condenser hotwell level be lowered to no less than two inches above the minimum level visible on the hotwell gage glass.

b. For planned idle periods greater than 2 weeks but less than 5 weeks and during which operation of the feed or condensate systems (requiring use of the condenser) is not scheduled, empty the hotwells following plant cooldown and keep them drained. However, if the plant is not cooled down, the condensers need not be drained.

c. For planned idle periods greater than 5 weeks and during which operation of the feed or condensate systems (requiring use of the condenser) is not scheduled, the following requirements apply:

   1 For saturated steam plant, drain and dry out the condenser (refer to paragraph 254-2.4.12.1.3).

   2 For superheated steam plants, drain the condenser. Drying is not required.

d. When makeup water is unavailable in port or there is a shortage of makeup water, the condensers need not be drained if the volume of water in the hot wells is needed for makeup water inventory management.

254-2.4.12.1.2 Draining the condensers will reduce the wetted surface area in the hot wells. This reduces the corrosion rate of the condenser shell by a factor of at least two and minimizes transport of corrosion products to the steam generators or boilers. This will minimize sludge buildup and fouling of heat exchanger heat transfer surfaces.

254-2.4.12.1.3 When steamside drying is required do it as soon as possible after the condenser has been secured to minimize condenser shell corrosion. Use an electrically heated air blower discharging into a hot well opening. The blower should have a filter on the inlet side to prevent foreign matter from entering the condenser shell. Allow the warm, moist air to escape from an upper shell or turbine exhaust casing opening. The steamside can also be dried by mechanical dehumidification equipment (refrigeration or desiccant type) discharging into a hot well opening and circulating the air. Use suitable filters to prevent steamside contamination by foreign matter or chlorides. Relative humidity should be less than 30 percent when the drying is completed. After drying, close the condenser openings. Check the condenser shell once a week and repeat the drying process if moisture is found inside.

**NOTE**

To avoid damage to an idle condenser and its associated turbine, all valves admitting steam to the condenser shall be secured during the lay-up period.

**CAUTION**

**If condenser waterbox vent valves are left open, flooding of the space through the vents is possible. To prevent flooding regularly inspect any condenser under seawater side lay-up.**

254-2.4.12.2 Seawater Side Lay-up. Lay-up requirements for the seawater side of condensers depend on the expected lay-up period:

a. Short-term lay-ups (1 week or less)

b. Midterm lay-ups (greater than 1 week but less than 4 months)

c. Long-term lay-ups (greater than 4 months)

254-2.4.12.2.1 For short-term lay-ups (1 week or less), fill the seawater side and circulate the seawater once a day for at least 10 minutes by running the circulating pump. For seawater systems with multispeed circulating pumps, use the highest pump speed. If the seawater cannot be circulated for 3 consecutive days, drain it and refill the condenser with freshwater (potable or feedwater quality water).

**NOTE**

During short-term seawater side lay-up, open the waterbox vents after the circulating pump and seawater inlet and discharge valves are secured. (If these valves leak, keep the waterbox vents closed.) If the overboard valves are left open after the circulating pump is secured, keep the waterbox vents closed.

254-2.4.12.2.2 If the condenser is to be idle for more than 1 week but less than 4 months, drain the seawater side as soon as possible and immediately fill it with freshwater (potable or feedwater quality water). After 2 to 3 weeks, drain the condenser and refill it with freshwater. (The initial freshwater fill may become deoxygenated and stagnant from the decay of organic matter.) Refill the seawater side with clean freshwater every month until operation or seawater side cleaning. After cleaning, leave the seawater side drained.

**NOTE**

If a condenser is laid up and filled with freshwater with the seawater inlet and discharge valves secured, open the vent valves to assist the relief valves in case pressure builds up inside the waterbox. Opening the vent valves also eliminates the possibility of condenser damage if a vacuum forms during cooldown of the freshwater fill. (If either the seawater inlet valve or the discharge valve leaks, keep the vent valves closed.)

254-2.4.12.2.3 If the condenser is to be idle for greater than 4 months, open and clean the seawater side as soon as possible. After cleaning leave the seawater side drained. If the condenser is not cleaned within 1 week after shutdown, lay up the seawater side according to paragraph 254-2.4.12.2.2 until it can be cleaned. When complete filling with freshwater is impossible, however, keep the seawater side wet by periodically (every 3 or 4 days) wetting down the tubes and tube sheet with freshwater. Keep the seawater side closed until it can be cleaned.

**NOTE**

The seawater side must be kept wet until cleaning to prevent drying of seawater side fouling. Some types of fouling, if allowed to dry and harden, may require chemical cleaning methods for complete removal.

254-2.4.12.2.4 To visually confirm that a condenser is filled with freshwater, install clear plastic tubing standpipes where the vent valve configuration permits. Install the standpipes so that the watchstanders can see water flowing through them. When the condenser is operating normally, the plastic tubing may remain attached to the condenser or be stored for future use. Install waterbox vent standpipes as follows:

1. Using standard hose clamps, attach a suitable length of clear tubing (Tygon or similar flexible plastic) to the vent outlet.
2. Extend the tubing above the condenser waterbox so that the water level is visible to watchstanders.
3. Bend the tubing and route it downward to a funnel connected to the space oily water drain system (where installed) or to the bilge.

254-2.4.13 BILGE DRAINAGE USING MAIN CIRCULATING PUMP. Using the main circulating pump for bilge drainage generally requires opening the bilge suction line stop or stop check valve, and then throttling the sea suction line valve to between 2/3 and 3/4 closed or until maximum bilge suction capacity is obtained. In some cases, pump and system characteristics are such that maximum bilge pumping capacity is obtained with the pump sea suction valve partly open or with the pump operating at less than full speed. Detailed procedures for obtaining maximum drainage of bilges differ among ship classes. The most effective operating procedure shall be established by trial and learned by frequent drill. Before drills, ensure that the bilges are clean to prevent contamination of the condensers.

254-2.4.14 OPERATION WITH NEWLY INSTALLED TUBES. Newly installed tubes are particularly susceptible to erosion/corrosion before a protective oxide film has completely formed. See paragraphs 254-2.6.15.1 and 254-2.6.15.2 for guidance in operating components with newly installed copper-nickel tubes.

254-2.4.15 SAFE OPERATING PRACTICES. The following general operating procedures will help prevent condenser damage:

1. Watch for air leaks in the vacuum system. If a large air leak develops, the condenser vacuum will be immediately and seriously reduced. Take corrective action immediately.

2. If a loss of vacuum is accompanied by a hot or flooded condenser, slow down or stop all units exhausting into the condenser until the condensing plant is again operating properly. Examine and lift by hand condenser shell relief valves (if fitted) before the condenser is operated or tested.

3. Do not subject surface ship condenser waterboxes to a pressure greater than 15 psig for ships built before 1950, or 20 psig for later ships. On deep draft ships such as aircraft carriers the allowable pressure may be slightly higher. Make sure that a relief valve is provided on the inlet waterbox of every condenser. Whenever the condensers are secured, examine these relief valves and lift by hand.

4. It is essential that adequate flow of circulating water be continuously provided when condensers are operating (paragraphs 254-2.4.7 through 254-2.4.8.3.1).

5. Keep the seawater side of operating condensers free of air.

6. Make sure that all surface ship main condenser circulating pumps have an effective bilge suction connection. Conduct regular drills to ensure that these pumps can be put on bilge suction quickly and effectively in an emergency.

7. Make no permanent connections between any condenser and a water supply system that could subject the seawater side to a pressure greater than the condenser circulating water system design pressure.

8. To guard against seawater contamination of the feed system, test the condensate from each main condenser every 15 minutes when underway, and every 30 minutes when standing by. Test the condensate from each operating auxiliary condenser every 30 minutes. Keep salinity indicator systems, when provided, in proper operating condition and under constant observation.

9. Make sure that condensate does not collect in condensers and overflow into turbines or engines.

10. Close all valves admitting steam to an idle condenser.

## 254-2.5 CONDENSER TROUBLESHOOTING GUIDE

254-2.5.1 Table 254-2-2 is a troubleshooting guide listing causes and remedies for low vacuum and condensate contamination of condensers.

## 254-2.6 MAINTENANCE

254-2.6.1 SAFETY PRECAUTIONS. The following precautions are essential to the safety of the ship and ship's force. Before performing maintenance on any component, refer to section 8 of NSTM Chapter 505 for safety precautions in isolating components from attached systems.

**WARNING**

**Hydrogen and other gases may accumulate in the steamside or seawater side of a condenser. This could cause serious injury or death by explosion or asphyxiation. Do not allow any open flame or spark-causing equipment near a newly opened condenser. Do not allow personnel to enter the condenser until it has been thoroughly ventilated and the space declared safe by the gas free engineer.**

a. Before entering a newly opened condenser, the gas free engineer shall test for combustible gas and hydrogen sulfide. NSTM Chapter 079, Volume 3, Damage Control - Engineering Casualty Control describes the test and necessary equipment. Observe all instructions supplied with each detection device. Improper use of any detection device could cause serious injury or death and could damage the condenser.

b. Before opening the seawater side of a condenser, tightly close and secure against accidental opening all sea connections, including the main injection, circulating pump suction, and main overboard stop valves. This prevents the possibility of a flooded engine room. Install safety gates, when provided. Before removing a manhole or handhole, drain the condenser seawater side through the drain valve in the inlet waterbox. This will ensure that all sea connections are tightly closed. Open vents if necessary to aid draining. If practical, replace and temporarily secure inspection plates when work is discontinued.

c. Do not subject surface ship condenser shells to a test pressure greater than 15 psig.

d. Drain the seawater side of a condenser before flooding the steamside, and keep the seawater side drained until the steamside is emptied.

e. Cognizant personnel shall closely supervise boiling-out operations. Inspect the condenser before and during the operation to ensure that all necessary safeguards are provided to protect personnel from scalding.

254-2.6.2 GENERAL MAINTENANCE PROCEDURES. Since condensers are a form of shell-and-tube heat exchanger, many of the maintenance procedures for condensers also apply to other types of shell-and-tube heat exchangers. For this reason, some of the following procedures include information on heat exchangers and condensers:

a. Inspect the entire surface of both tube sheets for leaks because more than one leak may be present. Determine whether a leak is in the tube wall or at the tube joint, when practical, so that it can be properly repaired.

**Table 254-2-2** CONDENSER TROUBLESHOOTING GUIDE

| Low Vacuum Reading | |
|---|---|
| **Cause** | **Remedy** |
| Defective instrumentation | Check the vacuum using an accurate manometer. |
| Insufficient flow of circulating water | Inspect the waterside of the condenser and the injection and discharge piping. Check the circulating pump performance. |
| Air blanket on the condenser waterside | Properly vent waterboxes so that all tubes run free. |
| Excessive air leakage | Test for air leaks, and seal any that are found. |
| High injection temperature | Calculate the performance on the basis of higher injection temperature. |
| Coating of tube steamsides or watersides by contaminants | Inspect and clean the tubes, as required, by mechanical or chemical means or both. |
| Faulty ejector operation | See Section 5. |
| Loss of sealing steam pressure to turbine glands | Check the sealing steam pressure and consult remedial action recommended in NSTM Chapter 231. |
| Improper drainage of condensate from condenser | Check the hot well water level and the operation of the condensate pump. |
| High-pressure turbine drain blowby | Check for trap malfunction or a leaking valve. |
| Condensate Contamination | |
| Cause | Remedy |
| Leaking tube-to-tube-sheet joint | Test to determine the location and re-expand tube or tighten packing. |
| Leaking tube | Test to determine the location and plug the tube until it can be replaced. |
| Leaking below condensate level or in pump suction lines | Test to determine the location and repair by recommended procedures. |
| Contaminated drains | Cut out drains one at a time and note the contamination level. Send drains to a less critical sump until repaired. |
| Defective instrumentation | Check the accuracy of the salinity indicator system. |

b. To minimize tube failure due to deposit attack, inspect and clean condenser tubes, tube sheets, and waterboxes at the following times:

1 Whenever access to the waterboxes is provided for the inspection of zinc protectors, if installed.

2 As soon as practical after the ship has operated in shallow or badly polluted water.

3 Before making a scheduled full-power run, if practical.

c. Keep zinc protectors, if installed, clean and tightly secured to ensure good metallic contact.

d. Inspect the baffles installed in condensers (to prevent steam and water erosion) whenever access is provided to the steamside, and whenever it is suspected that a steamside baffle has become dislodged or perforated. Check the baffles for damage and make sure they are secure in their proper location.

e. Take care not to damage tube holes in the tube sheets during tube removal or permanent tube-plugging operations.

f. Under no circumstances shall tubes or tube ends be heat treated or annealed by any naval activity before installation.

g. Take extreme care to avoid necking or crimping tubes when packing or calking tube joints.

254-2.6.3 CLEANLINESS. Foreign matter on the steam and waterside of the tubes interferes with and reduces the rate of heat flow from the condensing steam to the circulating water, thus reducing the vacuum. Except in extreme cases, the effect on vacuum at partial power is too small to be noticed. Even at full power the effect may be less serious than the damage done to tubes by lodging of foreign deposits. The effect of tube fouling on condenser vacuum becomes noticeable at high power levels when the seawater temperature approaches the design injection temperature for that condenser. Access to the seawater side and steamside of condensers varies with each unit. To carry out the following inspection and cleaning procedures, refer to the manufacturer's technical manual for access information.

254-2.6.4 INSPECTING THE SEAWATER SIDE OF CONDENSERS. Before opening the condenser seawater side, follow the safety precautions in paragraph 254-2.6.1. Inspect the condenser seawater side (tubes, tube sheets, and waterboxes) for fouling at the following times:

a. Whenever zinc anodes are checked.

b. Immediately after grounding the ship.

c. Whenever condenser performance indicates the possibility of tube fouling.

d. As soon as practical after operating in shallow or polluted water.

254-2.6.4.1 When waterbox inspection ports have been opened, place a light in one waterbox and inspect the tubes from the other end for any blockage or buildup of foreign matter on the inside surface. Since the tubes may be uniformly fouled, visual inspection alone does not reveal the extent of the fouling. Pass swabs or nonmetallic brushes or plugs through a sampling of tubes to determine the extent of foreign matter buildup in the tubes. When fouling by sand or mud is suspected, concentrate on inspecting the tubes in the lower portion of the condenser.

254-2.6.4.2 Boroscopic inspections are an improved method of visual inspection and should be used if such equipment is available.

**CAUTION**

**Condenser tubes are made of corrosion-resistant material that forms a protective oxide film on the seawater side. A scratch in this film can cause surface pitting. Never use abrasive or metal tools or wire brushes for cleaning tubes. Use all cleaning equipment carefully to avoid damaging the protective film.**

254-2.6.5 CLEANING THE SEAWATER-SIDE OF CONDENSERS. The following is the general procedure for cleaning the condenser seawater side:

1. Clean the tube sheet and the inside of the waterbox using freshwater and either a stiff nonmetallic brush or a plastic scraper. If oil is present, use a hot degreasing solution followed by a freshwater rinse (paragraph 254-2.6.6.4).
2. Remove material lodged in the tubes with an air or water lance, water gun, high-pressure water jet, or nonmetallic rod or scraper.
3. Clean the interior of the tubes using one of the methods discussed in the following paragraphs, depending on the type of fouling.

254-2.6.6 REMOVING SOFT FOULING. Soft fouling includes foreign matter such as sand, mud, oil, slime, and soft-bodied marine life that does not adhere strongly to tubes and can be easily removed. Use the following cleaning methods to remove soft fouling:

254-2.6.6.1 High-Pressure Water Jet. High-pressure water jetting is generally the best method for cleaning tubes (particularly 70-30 copper-nickel tubes on which fouling occurs more rapidly and is harder to remove than on 90-10 copper-nickel tubes). This method will remove all soft fouling and some types of hard fouling, such as salt scales and shells. Water jet cleaning equipment consists of a high-pressure pumping unit, high-pressure hose, three-way valve (usually foot-operated), and flexible lance with nozzle. To prevent any metal-to-metal contact in the tube, cover the wire braid flexible lance with a shrink-fit vinyl tube. The nozzle is designed to direct high-pressure water ahead of it (to clear any obstructions) and against the tube wall behind it (to clean the wall and propel the lance forward). Vary the operating pressure for each application depending on the type and amount of fouling present. Soft fouling might be removed with a 3,000-psig operating pressure, while hard fouling, like mussels, might require a 7,000-psig pressure. In any case, use only the minimum pressure necessary to remove the fouling. This will increase operator safety and extend the life of the tubes, the high-pressure hose, the flexible lance, and other system components.

**WARNING**

**Misuse of high-pressure water jet equipment can cause serious injury or death. Carefully read and follow all manufacturer's operating procedures, especially safety precautions.**

**CAUTION**

**To prevent damage to condenser and heat exchanger tubes and to the high-pressure water lance, do not exceed 7,000-psig discharge pressure on high-pressure water jet pumping units. If a component technical manual specifies a lower pressure do not exceed that pressure.**

254-2.6.6.1.1 The advantages of water jet cleaning are as follows:

a. Water jet cleaning is simple and reliable, and is not detrimental to tube material. One pass of the lance usually removes all foreign matter.
b. All tubes can be cleaned from one end of the condenser through the waterbox inspection opening.
c. This method avoids the possibility of plugs or brushes becoming lodged in tubes.
d. Pressure will not build up in the tube even if the tube is completely blocked.

254-2.6.6.1.2 Observe the following safety precautions during setup and performance of water jet cleaning operations:

1. Ensure that all operators are thoroughly trained in the operation of water jet equipment and the requirements and hazards of the particular function they are to perform in the water jetting operation.

2. Ensure that all maintenance operations comply with Navy Safety Requirements for Forces Afloat, OPNAVINST 5100 series.
3. Never point the lance at any part of your body, at any person, or at any object other than the subject of the water jet operation.
4. Under no circumstances attempt operation of the water jet equipment alone. The immediate presence of someone capable of rendering assistance is required.
5. First Aid - Never let an injury, no matter how slight, go unattended. Always obtain first aid or medical attention immediately. If bodily injury occurs on contact with the jet stream, seek immediate hospital attention, regardless of how insignificant the injury may appear on the surface. Extensive internal damage may result from such an injury and may not be apparent from a surface wound. Water jet lacerations can also induce air into the bloodstream. Inform the medical staff of the cause of the injury.
6. Maintain remote communications between the pump operator and the lance operator. This is essential for safe operation of the water jet equipment. If communications are interrupted at any time, shut down the pump unit until communications are restored.
7. Use only low voltage lighting in the waterbox of the unit being cleaned.
8. Never operate water jet equipment without protective equipment. All operators should wear a hard hat, face shield, rain suit, gloves, and rubber boots with nonskid soles over safety-toed shoes.
9. Before use, always check the control gun trigger for proper mechanical operation.
10. Always operate the control gun with two hands.
11. Never tie or wedge the water jet control gun trigger in the ″energized″ or ″on″ position.
12. Maintain sound footing for safe operation of the water jet equipment. Always use a proper stance and brace for gun recoil before pressurizing the control gun.
13. Post warning barriers around the area where jetting operations are being conducted.
14. Never interfere with the operators during high-pressure jetting operations.
15. Use the minimum operating pressure required for the cleaning job. This provides maximum operator safety and comfort.
16. Never remove the nozzle from the heat exchanger tube unless the control gun trigger has been released. The high-pressure spray could injure personnel. Mark the lance with either tape or waterproof pen at two locations. Place a stripe approximately 4 inches from the nozzle connection to indicate the nozzle location with respect to the tube and to prevent accidental water jet nozzle withdrawal from the tube. Place a second stripe a distance from the nozzle connection equal to the full length of the tube minus 6 inches. This will ensure that the nozzle does not travel beyond the opposite tube sheet.

254-2.6.6.2 Brushes or Plugs. Nonmetallic bristle brushes or rubber plugs can be blown through tubes using a water gun or lance, followed by a water flush. For small heat exchangers, use a nylon brush on the end of a nonmetallic rod to clean each tube manually.

**NOTE**

Strictly account for each plug and brush to ensure that none of these devices remain in the condenser or heat exchanger after cleaning.

**WARNING**

**Built-up air pressure in a blocked tube can propel objects in the tube back at the gun operator at a dangerously high speed when the gun is pulled out of the tube end. Make sure that guns using air pressure are equipped with a pressure relief valve to vent back pressure in a blocked tube.**

254-2.6.6.3 Air or Water Gun. An air or water gun or lance can be used to clear tubes that are blocked by mud or sand.

**WARNING**

**Trisodium phosphate is a strong alkali that can cause chemical burns of the skin or eyes. Always wear rubber or plastic gloves, goggles or plastic face shields, rubber or plastic aprons, and boots. In case of skin contact, thoroughly flush the affected area with freshwater. If eye contact occurs, allow freshwater to flow into the opened eyes for 15 minutes. Get immediate medical attention.**

254-2.6.6.4 Degreasing Solution. To remove oil, grease, and slime from the seawater side, use a degreasing solution as follows:

1. Using freshwater prepare a solution of 2 to 3 percent (by weight) of trisodium phosphate anhydrous (O-S-642, Sodium Phosphate, Tribasic, Anhydrous; Dodecahydrate; and Monohydrate; Technical, type 1, 100-pound drum - NSN 6810-00-664-7487) with 1 percent (by weight) of liquid nonionic detergent (MIL-D-16791, Detergents, General Purpose (Liquid Nonionic) 1 gallon - NSN 7930-00-282-9699).
2. Heat the solution and circulate it through the seawater side for 2 to 3 hours. The solution temperature should be at least 140°F.
3. Follow the degreasing with a thorough freshwater flush.

**NOTE**

A higher solution concentration and temperature may be required depending on the amount of fouling.

254-2.6.6.5 Knotted Rope. Nonmetallic knotted rope may be used to remove soft fouling from tubes. Size the rope so that when knotted, the knots are slightly larger than the tube inside diameter and a slight compression of the knots occurs when the rope is pulled through the tube. The scrubbing action between the knots and the tube surface will remove excess marine growth, dirt, and soft scale from the tube wall.

254-2.6.6.5.1 Use a length of rope approximately twice as long as the longest tube in the condenser or heat exchanger. Tie three knots in the middle of the rope, spacing them about 1 foot apart. Attach one tube length of leader to one end of the rope. (If wire is used as a leader, insulate the wire and tape the connections and exposed end of the wire to prevent scratching the inside tube surface.)

254-2.6.6.5.2 Feed the lead wire through the tube and pull until the knots are inside the tube, then pull the rope back and forth through the tube to remove marine growth. Repeat these steps for each tube to be cleaned. After cleaning, flush all tubes with water. Replace the rope when wear or fraying is apparent.

254-2.6.6.6 Phenolic Disk Scraping Tool. The phenolic disk scraping tool shown in Figure 254-2-5 is effective in removing accumulated mud, grass, and loose scale from inside tubes. Assemble the scraping tool by stacking the disks and securing them together, loosely, on a section of 1/16-inch insulated wire that is looped, taped, and fastened to an insulated lead wire. The lead wire attached to each end of the disk assembly should extend the full length of the tube with enough additional length to allow gripping of the free end.

**NOTE**

Plastic disks may jam or break, and may be difficult to retrieve.

254-2.6.6.7 Rotary Brush. Rotary nylon brush cleaning is a safe and effective method for removing all soft fouling and loose debris inside straight tubes. It can be performed by one person and requires access to only one end of the heat exchanger. In many cases, all tubes can be cleaned through the waterbox inspection opening or piping connections using rotary brush equipment.

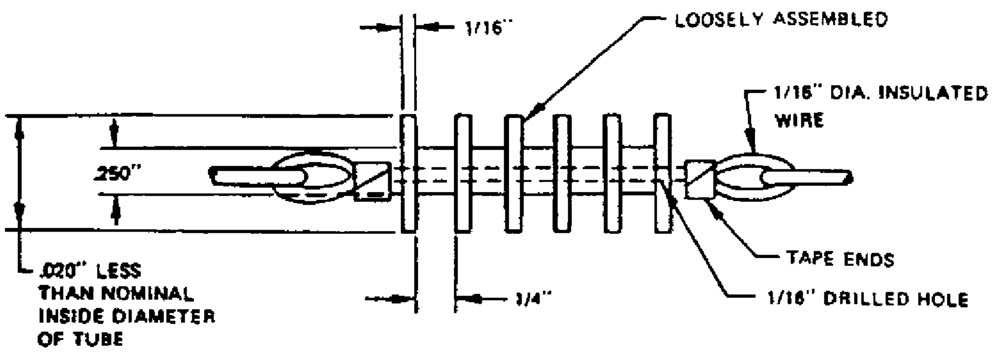



Figure 254-2-5. Phenolic Disk Scraping Tool

**CAUTION**

**Do not use centrifugally-actuated expanding brushes, brushes with metallic or ceramic bristles, or brushes with abrasive impregnated nylon bristles. Use only straight brushes with spiraled nylon bristles.**

**CAUTION**

**Rotary brushes shall have a plastic covered tip. Do not operate the rotary brush in the U-bends of tubes because the brush tip will damage the tube walls. Carefully insert the rotary brush into the tubes to prevent the brush tip from scratching tubes or tube sheet.**

254-2.6.6.7.1 Rotary nylon brush equipment consists of an electric or air powered drive unit, a flexible shaft in a non-metallic (nylon) casing, a foot switch, and a straight brush with spiraled nylon bristles and plastic covered tip. While the flexible shaft and nylon brush rotate, freshwater flows between the flexible shaft and its casing to flush debris out of the tube. The foot switch simultaneously activates the rotating brush and the flushing water. Refer to Table 254-2-3 for requirements for rotary nylon brush cleaning equipment.

**CAUTION**

**Flexible shafts for rotary brush equipment will break if kinked or bent at too small a radius. Always uncoil the shaft as much as possible before operating. Use a small bend radius only when absolutely necessary. Do not bend the flexible shaft within 4 feet of its connection to the drive motor while operating.**

**CAUTION**

**Flexible shafts will break if forced into the tube. If resistance is met while feeding the brush into the tube, stop feeding immediately and withdraw the brush. Do not force the brush to clear any blockage or resistance, tube damage may result from the distorted brush or the brush may become jammed in the tube.**

254-2.6.6.7.2 When used on light to medium fouling (mud, seaweed), one pass through a tube using about a 1 to 2 foot per second feed rate will sufficiently clean the tube. A slower feed rate and more passes are typically necessary for heavy fouling, especially when barnacles are present. During rotary brush cleaning, inspect the brush periodically (such as after every ten tubes or after blockage is encountered). Remove excessive debris and replace worn brushes as necessary.

**Table 254-2-3** ROTARY NYLON BRUSH CLEANING EQUIPMENT SPECIFICATIONS

| Feature | Specification |
|---|---|
| Drive unit size & weight (for portable units) | Portable drive units must be small enough to fit through a 25″ hatch and weigh 40 lbs or less so it can be carried by one person. |
| Flexible shaft | The flexible shaft must have a non-metallic casing. Any metal parts which could contact the tube i.d. shall be covered with a non-metallic material to prevent tube damage. |
| Rotary brush type | 1. The only type of brush authorized for use is a straight brush with spiraled nylon bristles. The tip and any other metal part of the brush which could contact the tube i.d. shall be covered with a non-metallic material to prevent tube damage.<br>2. Centrifugally actuated expanding brushes, brushes with metallic or ceramic bristles, or brushes with abrasive-impregnated nylon bristles are not allowed. |
| Rotary brush size (diameter) | Brush diameter should be between 1/16 inch smaller and 1/16 inch larger than the tube’s nominal inside diameter. |
| Rotary brush rotational speed | The flexible shaft and nylon brush must be capable of one or more rotational speeds between 500 and 2000 revolutions per minute. |
| Foot switch | The foot switch must be non-electric or sufficiently waterproofed to prevent electric shock. |

**Table 254-2-3** ROTARY NYLON BRUSH CLEANING EQUIPMENT

SPECIFICATIONS - Continued

| Feature | Specification |
| --- | --- |
| Water requirements (freshwater) | The inlet water pressure required must not be greater than 40 psig. |
| Power Requirements | |
| Electrical requirements<br>or<br>Service air requirements | The unit must operate on 120V, 60 Hz power and shall be equipped with a ground fault circuit interrupter for electric shock protection.The unit must not require more than 100 psi, 80 CFM service air. |

254-2.6.7 REMOVING HARD FOULING. Hard fouling is foreign matter that adheres strongly to the tube and cannot be easily removed. This type of fouling includes barnacles, sea scales (such as calcium carbonate) that may deposit in the tube during extended periods of no or low seawater flow, and hard coatings and oxide films that may coat the tube during extended periods of intermittent operation in shallow or polluted water. The following methods can be used for the complete or partial removal of hard fouling.

254-2.6.7.1 High-Pressure Water Jet. High-pressure water jet cleaning (paragraph 254-2.6.6.1) can remove some types of hard fouling. More than one pass of the lance, however, may be required for complete removal.

254-2.6.7.2 Acid Cleaning. Acid cleaning will remove all types of hard fouling. Because of the potential hazards to material and personnel, however, consider acid cleaning only when other cleaning methods are ineffective. Only a naval shipyard or other qualified activity shall perform acid cleaning. Detailed procedures and guidance for acid cleaning can be found in NSTM Chapter 531, Volume 1. General procedures are as follows:

a. Never use uninhibited acid solutions.

b. Take care that all materials that will come in contact with the acid solution are compatible with the solution being used. Before cleaning remove any materials that would be damaged by the acid. If the compatibility of materials is unknown, confirm it by testing and examination.

c. Sulfamic acid is preferred over hydrochloric acid for shipboard acid cleaning because it is safer.

d. If a significant amount of oil, grease, or slime is present in addition to hard fouling, consider using a degreasing solution before acid cleaning.

e. Before acid cleaning main and turbogenerator set condensers of fossil-fuel-powered ships, obtain guidance from the Naval Ship Systems Engineering Station (NAVSSES).

**NOTE**

Approval of the Naval Sea Systems Command (NAVSEA) is required before acid cleaning the seawater side of saturated steam plant main and turbogenerator set condensers. Submit procedures for acid cleaning these condensers to NAVSEA for approval before performing this work. If technical manuals for saturated steam plant heat exchangers contain procedures for acid cleaning, use those instead of the guidance provided here.

254-2.6.7.3 Nonmetallic Rods. Nonmetallic rods can be used to partially remove hard fouling. Follow this procedure with a thorough flushout.

254-2.6.8 BLOCKED TUBES. For single-tube-sheet (conventional) condensers and heat exchangers, remove blocked tubes that cannot be cleared from service. This is done by plugging the tube ends with tapered phenolic plugs. For double-tube-sheet (saturated-steam plant) condensers and heat exchangers, replace or permanently plug any blocked tubes that cannot be cleared. If there is insufficient time for replacing or permanently plugging them, temporarily plug the blocked tubes with tapered phenolic plugs. Install permanent tube plugs (or replace the tubes) at the first opportunity. Paragraphs 254-2.6.26 through 254-2.6.29 provide details on tube plugging.

254-2.6.9 INSPECTING THE STEAMSIDE OF CONDENSERS.

254-2.6.9.1 Annual Visual Inspection. As access permits, give the steamside of the condensers a detailed, annual visual inspection. Pay close attention to the following areas:

a. Tubes and shell structure near the turbine exhaust connections.

b. Tubes and internals near the discharge of the steam dump and auxiliary exhaust connections, high-pressure drains, turbine drains, and continuous flow drains such as air-conditioning and distilling plant drains.

c. The condition and structural integrity of internal drain lines and impingement baffles.

254-2.6.9.1.1 Take corrective action if the visual inspection indicates that any of the following conditions are present and active:

a. Noticeable metal loss from the shell, baffles, internal drain lines, or internal structures.

b. Loose or cracked impingement baffles.

c. Cracked or broken baffle attachment welds.

d. Noticeable metal loss from unplugged tubes near baffles. (Erosion will initially appear as sandpaper-like roughening of the tubes.)

254-2.6.9.2 Eddy Current Inspection. Periodically eddy current inspect the tubes of main, turbogenerator, and seawater-cooled air ejector condensers serving saturated-steam plants as directed by NAVSEA Instruction 9254.1.

254-2.6.9.2.1 Before an eddy current inspection, clean and dry the tubes to increase inspection probe life, reduce signal fluctuations, and improve tube condition interpretation. Take the following steps to prepare tubes for eddy current inspection:

1. Clean the tubes using a high-pressure water jet with a discharge pressure of 5,000 to 7,000 psig (paragraph 254-2.6.6.1. A dummy eddy current inspection probe can be used to verify that the tube ends have been adequately cleaned.

2. Air blast each tube for at least 30 seconds with 100- to 150-psig air.

3. Circulate hot air through the tubes (through a waterbox opening) until the seawater side is dry.

4. Verify that the tubes are clean and dry before eddy current inspection.

254-2.6.9.3 Cleanliness Inspection. Before entering the condenser steamside, make sure that all safety precautions in paragraph 254-2.6.1 are followed. Visually inspect the steamside of condensers for cleanliness after steamside repairs, when steamside contamination is suspected, and during ship overhaul. Where visual inspection is impractical, flush the condenser steamside with freshwater of feedwater quality to ensure that cleanliness criteria are met.

**WARNING**

**Trisodium phosphate is a strong alkali that can cause chemical burns of the skin or eyes. Always wear rubber or plastic gloves, goggles or plastic face shields, rubber or plastic aprons, and boots. In case of skin contact, thoroughly flush the affected area with freshwater. If eye contact occurs, allow freshwater to flow into the opened eyes for 15 minutes. Get immediate medical attention.**

**NOTE**

The officer in charge of the station shall inspect all boilout and drainage arrangements, before and during boilout, to safeguard against accidents and ensure the safety of the personnel engaged in this work.

254-2.6.10 CLEANING THE STEAMSIDE OF CONDENSERS. If oil, grease, or preservative is in the steamside, boil out the condenser shell using the following procedure:

1. Drain and clean the seawater side.

2. Blank off or secure the valves in all lines connected to the condenser steamside.

3. Add chemicals in the following amounts for every 1,000 gallons of feedwater added to the steamside:
   a 100 pounds of trisodium phosphate anhydrous (O-S-642, type 1, 100-pound drum - NSN 6810-00-664-7487)
   b 1 quart of liquid nonionic detergent (MIL-D-16791, 1 gallon - NSN 7930-00-282-9699)

4. Fill the steamside of the condenser with freshwater above the top row of tubes unless water at this height will overflow into the turbine exhaust trunk when brought to boiling. (In such cases either regulate the height so that the boiling water will not overflow or, preferably, blank off the exhaust connection.)

5. Introduce live steam into the condenser through the boilout connection and bring the solution to the boiling point at atmospheric pressure. (Take care that the condenser is vented to the atmosphere during this operation and that pressure does not build up in the condenser shell.)

6. Boil the solution for about 6 hours or as long as necessary to remove the contamination. Circulate the solution during boiling, if practical. Continuously introduce sufficient steam to ensure that boiling is maintained. The vibration and noise resulting from admitting live steam to the condenser shell does not necessarily indicate that boiling is taking place.

**WARNING**

**Never attempt to drain the spent solution from a condenser or heat exchanger by loosening inspection or access covers on the hot wells. The hot solution could scald personnel.**

7. Drain the condenser by pumping the solution to a waste or storage tank. Disposal shall conform to local regulations. Do not pump hot solution to the bilges or overboard.

8. Flush out the condenser several times with freshwater. Remove an inspection plate near the bottom of the condenser and hose out all the sediment in the bottom of the hot well.

9. If the contaminant has not been completely removed, repeat the boilout procedure.

10. Test the condenser for leaks.

254-2.6.11 SEAWATER TIGHTNESS. One of the most serious machinery derangements aboard steam-propelled ships is the failure of even one of the thousands of tubes installed in the condenser. This can result in seawater (chloride) contamination of the condensate. Information on the maximum chloride contamination allowed for condensate can be found in NSTM Chapter 220, Volume 2. Seawater leakage from a tube or tube sheet at rates as low as 0.0001 gpm can exceed the maximum chloride limit at normal cruising rates. As a boiler is steamed, it acts as a concentrator for the steam system, accumulating the dissolved and suspended contaminants in the condensate and feedwater. In a main propulsion boiler operating at 50 percent of rated capacity, the contaminant concentration in the boiler water will increase tenfold every hour. Even small condenser leaks can thus seriously contaminate the boiler and, over time, totally disable the machinery plant.

254-2.6.11.1 Seawater Contamination. Watchstanders shall make every effort to guard against seawater contamination of the condensate system. To accomplish this most ships have salinity indicator systems, as described in NSTM Chapter 220, Volume 2. In addition to monitoring these indicating systems, watchstanders should periodically compare them with chemical titration results, as required by NSTM Chapter 220, Volume 2, to ensure their accuracy.

254-2.6.11.2 Sources of Seawater Leakage. The most probable sources of seawater leakage into the condenser are:

a. The piping or joints connected to the condenser. These are normally under vacuum and at times are submerged in the bilge. A typical example would be a makeup feed pipe between a feedwater tank and the condenser.

b. Contaminated freshwater or low-pressure steam drains that are alined to the condenser by vacuum drag through the freshwater drain collecting tank.

c. Tube end leaks either between the external tube wall and the tube sheet, or through the tube sheet packing. (This is not a factor in double-tube-sheet condensers.)

d. Tube perforations.

e. A leak path under a waterbox/tube sheet flange gasket, through the clearance holes in the flange bolting, and under the tube sheet/shell flange gasket into the condenser shell. (This is not a factor in double-tube-sheet condensers in which the inner steel tube sheet is welded to the shell, eliminating the gasketed joint.)

254-2.6.11.3 Locating Condenser Seawater Leakage. Seawater leakage cannot always be detected by the conductivity-type salinity indicators in the condensate system because the amount of condensate flowing is usually too large. The first indication of chloride contamination in the condensate may be a chloride buildup in the boiler water or in the condenser hot well after the main engine has been secured.

254-2.6.11.3.1 Once seawater contamination of the condenser has been confirmed (by a chemical titration test of a sample taken from the condenser hot well), take immediate steps to minimize its effects as described in NSTM Chapter 220, Volume 2, and the Engineering Operational Casualty Control (EOCC) section of the Engineering Operating Procedure (EOP). In all cases locate and isolate the source of the contamination. Of the five possible sources of seawater contamination listed in paragraph 254-2.6.11.2, investigate a and b first. If the chloride contamination has not yet reached a serious level in the steam generator, isolate all sources of makeup feed and the steam drains from the condenser. Take samples from these sources and test them for contamination. Pump out the bilges to ensure that bilge water is not the source of contamination. With the makeup feedwater and the freshwater drain collecting tank isolated from the condenser, draw samples from the hot well and test them for chloride. If over time the chloride level in the hot well fails to decrease and no samples from the steam drains and feed tanks indicate the source of the contamination, assume that the contamination is from the condenser circulating water system. Secure the condenser at the earliest opportunity.

254-2.6.12 TEST FOR SEAWATER LEAKS. Before beginning any test work, review paragraph 254-2.6.1 and ensure that all safety precautions are observed. The following paragraphs describe five methods of locating leakage between the circulating water system and the steamside of the condenser, and an additional method for detecting tube-to-outer-tube-sheet joint leakage in double-tube-sheet condensers. The method used will be dictated by operational considerations, the severity of the leak, and the resources at hand. Methods 1 and 2 are effective in detecting gross leakage and in most cases one of them should be the first method attempted. Method 3 is used to detect and locate leaks that may be depth and temperature sensitive. Because the effectiveness of method 3 depends largely on access to the steamside of the condenser, accurately pinpointing the leak may require further testing using either method 4 or method 5. If method 3 is to be used after method 1, do not use the fluorescein dye with method 1 as that would prevent effective use of the dye with method 3.

254-2.6.12.1 GENERAL. Methods 4 and 5 involve leak testing individual tubes, which can be a time-consuming process. One of the following steps may eliminate or reduce the time required to test individual tubes:

a. Review the most recent eddy current inspection reports.

b. Conduct an eddy current inspection to locate leaking or suspect tubes. Saturated-steam plant ships should carry the most recent 100 percent and partial eddy current inspection reports.

254-2.6.12.2 Method 1. The object of this test is to locate leakage by pressurizing the steamside of the condenser with freshwater and inspecting for leakage at the tube sheet joints and inside the tubes. Using halide-free sodium fluorescein dye with this method will enhance the sensitivity of the test. The procedure is as follows:

1. Drain the seawater side of the condenser and remove the waterbox inspection plates.
2. Ventilate the seawater side of the condenser.
3. Wash the waterbox, tubes, and tube sheets, and dry the tubes and tube sheets using compressed air.
4. Before filling the steamside with water, make sure that all isolation valves in the piping connected to the condenser shell are closed.

5. Remove the access plate from the turbine casing or condenser shell to allow access to the steamside of the condenser.

**WARNING**

**Do not allow the deaerating feed tank (DFT) shell temperature to exceed 200°F. Hot feedwater released to the condenser when access plates are removed could vaporize and injure personnel.**

6. Use warm water with this test to avoid condensation on the tube sheets or in the tube ends since condensation can erroneously indicate a leak. To fill the condenser with warm water, aline the DFT for recirculation and circulate the water in the DFT until the shell temperature is approximately 130°F.
7. Seal the gland areas in the high- and low-pressure turbines by packing rags around the shaft (between the bearing housing and the labyrinth seal packing boxes) and sealing the area with pressure-sensitive tape. A more effective sealing method is to install a bicycle inner tube in this area and inflate it to give a positive seal. First cut the inner tube and seal each cut end with a knot or by vulcanizing. Wrap the inner tube around the turbine rotor shaft and inflate it.
8. Open the rundown valves from the DFT and backfill the condenser with warm feedwater.

**CAUTION**

**Some fluorescein dyes contain chlorides. To prevent the possibility of chlorides contaminating the feed system, use only halide-free sodium fluorescein ($C_{20}$ $H_{10}$ $Na_2$ $O_5$ ) for this test.**

9. If using fluorescein dye with this test, obtain the proper dye from Fisher Scientific Co., 711 Forbes Ave., Pittsburgh, PA., Chemical Index Catalog A-833. It is available in powdered form in quantities of 100 or 500 grams. Premix the dye with feedwater (3 grams of dye per 1000 gallons of water) and add it through the shell access as you fill the condenser. The amount of feedwater required to fill the condenser is listed in the design data section of the condenser technical manual. Obtain the data for the condenser flooded weight (circulating water drained) and the condenser dry weight. Calculate the feedwater required as follows:

   (Flooded Weight - Dry Weight)/8.33 = Gal Feedwater Required. The feedwater required can also be determined by observing changes in the DFT level as you fill the condenser.
10. When the feedwater covers the top of the tube sheet, close the DFT rundown valve. Take care when filling the condenser so as not to flood the turbine.
11. Make sure that the cutout valves to the condenser vacuum gages are closed, then apply air pressure. Do not exceed 15 psig. To do this install a temporary access plate (modified to allow connection to the ship service air supply) over the turbine casing or condenser shell access opening.
12. Inspect both tube sheets from the circulating-water side for evidence of leakage around the tube joints or in the tubes. If fluorescein dye was used, illuminate the area with an ultraviolet lamp that has been properly grounded and authorized for shipboard use. Be sure to inspect the underside of the condenser shell, the hot well, and system piping joints since these areas could be sources of bilge water contamination.
13. When the hydrostatic test has been completed, drain the steamside and flush all traces of fluorescein dye from the condenser. Fluorescein dye poses no special environmental hazards but consult the Senior Officer Present Afloat (SOPA) regulations before discharging it into the harbor.

254-2.6.12.3 Method 2. This method involves pressurizing the steamside of the condenser with air and inspecting for air bubbles coming from the tube sheet as the circulating-water side slowly fills with water. The procedure is as follows:

1. Drain the condenser circulating-water side, and remove the waterbox inspection plates.
2. Seal the gland areas as described in paragraph 254-2.6.12.2, step 7.
3. Make sure that the cutout valves to the condenser vacuum gages are closed.
4. Make a temporary access cover equipped with a pressure gage and several air hose connections for the steamside access opening.
5. Install the access cover on the steamside access opening and connect the air hose to the ship service air supply. Using multiple air supplies will reduce the time needed to pressurize the condenser.
6. Pressurize the steamside of the condenser to not more than 15 psig.
7. Slowly fill the circulating-water side while watching the surface of the water near both tube sheets for air bubbles. Bubbles indicate leaks.
8. Use a candle flame or soap solution to inspect points in the underside of the condenser shell and hot well that could be exposed to bilge water contamination.
9. Gross leakage should be noticeable immediately. Smaller leaks, especially in a tube, may require time and close observation to detect. Note the trim or list of the ship, and closely watch the high-end tubes. If the drawing of the condenser indicates that the tubes are intentionally bowed, consider this fact when inspecting for leaks. This method cannot be used to find a leak in tubes located above the lower edge of the highest waterbox inspection opening.

254-2.6.12.4 Method 3. This method is suitable for detecting very small leaks in condensers. Because the design pressures of condenser waterboxes on surface ships are only slightly greater than the hydrostatic test pressure used in methods 1 and 2, this method has little advantage over methods 1 and 2 and is not normally used for surface ship condensers. Consider using this method only after method 1 (without fluorescein dye) or method 2 has proved unsuccessful or after an eddy current inspection of the tube bundle has failed to identify leaking or suspect tubes. In many cases method 3 will provide only the general location of the leak, and pinpointing the leak exactly will require methods 4 or 5 or an eddy current inspection of all tubes in the condenser. Materials needed for method 3 are listed in Table 254-2-4.

**NOTE**

Method 3 requires access inside the condenser shell to locate the area of leakage. Additional tests may be required to pinpoint the exact location of the leak.

1. Close the condenser main injection and overboard valves and take all necessary steps to ensure against unauthorized opening.
2. Open the waterbox drain and vent connections and drain the seawater side of the condenser.
3. Pump all water from the condenser hot well. During the test the hot well may become contaminated.
4. Remove manhole and inspection plates from the condenser shell and hot well to permit maximum access to the condenser.

5. Ventilate the steamside of the condenser using the ship's portable blower.
6. Check clothing and shoes of personnel entering the condenser to ensure that no fluorescent material is carried into the condenser.
7. Using the ultraviolet light, inspect the steamside of the condenser, as far as access permits, and the waterbox flanges for evidence of fluorescent material before conducting the test.
8. Make sure that the cutout valve in the line to the waterbox relief valve, if installed, is open and that the relief valve is not gagged.
9. Open the drains from the void between the double tube sheets and place containers under the drains to collect any water emitted during the test.
10. Locate the mixing tank near the condenser or topside, as space permits, ensuring that the bottom of the mixing tank is above the waterbox vent valves.

**Table 254-2-4** TEST METHOD 3 EQUIPMENT LIST

| Quantity | Equipment List | Capacity |
|---|---|---|
| 1 | Mixing tank with 1-1/2 inch valve on bottom outlet | 190 to 750 liters (50 to 200 gallons) |
| 3 | Hand-held ultraviolet lights (Lights shall be suitable to protect personnel from electric shock according to MIL-L-22569, Light, Ultra-Violet, Fluorescent, Portable.) | |
| 1 | Tank lighter or tank truck sufficiently clean to permit storage of dye mixture (identified in Method 1) for use in repeating test | Sufficient to dispose of dye-water mixture used in test |
| Sufficient | Food or paint cans with handles, clean and checked under ultraviolet light to ensure that no fluorescent material is present (Locate cans under double-tube-sheet space drains and condenser air baffle drains.) | 1.9 liters (1/2 gallon) |
| 1 | Ventilation blower and hose for ventilating steamside of condenser | |
| 1 | Pump suitable to apply hydrostatic test pressure to seawater side of condenser and necessary pipe and fittings | |
| 1 | Small spray pump and tank similar to that used to spray plant insecticide (This will be used to lightly wash down condenser tube bundles to indicate presence of any dye in amounts too small to pass through tube bundle.) | |
| Sufficient | Valves (designed for hydrostatic test pressure), hose, and fittings to connect compressed air source to condenser waterboxes (Equipment will be required to empty dye-water mixture from seawater side of condenser.) | |
| Sufficient | Fittings necessary to attach 1-1/2 inch suction-type hose to condenser waterbox drain | |

**Table 254-2-4** TEST METHOD 3 EQUIPMENT LIST - Continued

| Quantity | Equipment List | Capacity |
|---|---|---|
| Sufficient to reach from mixing tank to condenser waterbox drain or from condenser waterbox drain to tank lighter or tank truck | 1-1/2 inch suction-type hose | |
| Sufficient | Hose from a freshwater mixing tank (Hose shall be at least a 1-1/2 inch fire hose and will be used to fill mixing tank.) | |
| 1 | Pump | Capacity and head characteristics suitable to pump dye-water mixture stored in tank lighter or tank truck to mixing tank |
| 1 | Centrifugal pump | Capacity and head characteristics suitable to pump dye-water mixture from condenser to tank lighter or tank truck (for surface ships or submarines when compressed air called for is unavailable or cannot be used) |
| Sufficient | Hose | Enough to carry dye-water mixture from tank lighter or tank truck to mixing tank |

**NOTE**

Since extremely small concentrations of this dye are detectable under ultraviolet light, place the mixing tank so as to minimize the possibility of tracking or spilling any dye-water mixture into the engine room where it could be picked up by the clothing of personnel and carried into the condenser.

11. Fit a 1-1/2 inch outlet valve in the bottom of the mixing tank. Connect a 1-1/2 inch hose between this outlet valve and a convenient waterbox drain valve. An adapter may be required for this connection.
12. Connect the outlet hose of the hydrostatic test pump to the drain valve in the opposite waterbox. An adapter may be required for this connection. The hydrostatic test pump should be supplied with clean freshwater.
13. Close all waterbox drains except the one to which the hose from the mixing tank is attached. Open all waterbox vent valves.
14. Close the mixing tank outlet valve and fill the mixing tank with freshwater.
15. Open the mixing tank outlet valve and fill the condenser waterboxes with approximately 50 gallons of freshwater (to which no dye has been added). Inspect all valves and hose connections for leaks and correct as necessary.

**NOTE**

Making sure that all joints in the system are tight to prevent the dye from leaking.

16. Fill the mixing tank with water and add 3 grams of dye (identified in Method 1) for every 1,000 gallons of water. Mark the mixing tank level to allow repeated fillings with water and the addition of dye.
17. Open the mixing tank outlet valve, and drain the dye and water mixture from the mixing tank to the con-

denser. Repeat until the dye and water mixture flows from the waterbox vents. Close the mixing tank outlet valve, the inlet waterbox drain valve, and all waterbox vent valves.

18. Open the waterbox drain valve connected to the hydrostatic test pump and start the hydrostatic test pump.
19. Pressurize the circulating-water side of the condenser to 100 percent submergence pressure or seawater system design pressure, as appropriate. Cycle this pressure as follows:
    - a Six hours at design pressure.
    - b Six hours at 50 percent of design pressure.
    - c Six hours at 10 percent of design pressure.
    - d Six hours at design pressure.
20. Using the ultraviolet light, inspect accessible areas of the condenser steamside while the circulating-water side is pressurized. Make sure that persons entering the condenser carry no fluorescent material with them on their clothing or shoes.
21. While the circulating-water side is pressurized, frequently inspect for evidence of leakage to the steamside, the outside of the waterbox and circulating water system, and the containers placed under the drains. Leaks must be detected as soon as possible since the spread of fluorescent dye will make locating additional leaks difficult.
22. After the 24-hour pressure cycle, shut off the hydrostatic pump.
23. Using the least amount of water possible, spray water on the outside of the tube bundles of the large condensers to wash out any dye. Use a small spray pump and tank such as a garden insecticide sprayer.
24. After completing the test, disconnect the hose from the mixing tank outlet valve and connect it to the suction of a portable pump. Place the portable pump so as to ensure adequate submergence. Open the waterbox drain valve and flood the pump suction before starting the pump. Pump the dye-water mixture to a waste barge or shore facility. Consult SOPA regulations for final disposal of the dye-water mixture.

254-2.6.12.4.1 If the test procedure described in method 3 indicates leakage but the exact location cannot be found, a pressure drop test of individual tubes will be required. There are two such tests. Method 4 uses water as the test fluid and method 5 uses nitrogen. Both methods require special test equipment and should normally be performed by an Intermediate Maintenance Activity (IMA) or shipyard. Experience has shown that nitrogen can detect smaller leaks than water. Using nitrogen, however, is much more time consuming. The best method to use depends on the circumstances of each case.

254-2.6.12.4.2 Conduct an eddy current inspection of individual tubes before proceeding with method 4 or 5. When using method 4 or 5, inspect the most leak-prone areas of the condenser first: the periphery of the tube bundle, the air-cooling section, and areas near the inlets to the condenser, such as auxiliary exhaust dump valves, makeup feed lines, and condensate lines. Also review past eddy current inspection reports for indications of suspect areas.

254-2.6.12.5 Method 4. This test involves pressurizing each tube individually with water to 400 psig. Table 254-2-5 lists the equipment required for this test. The hydrostatic test assembly used for this test is described in detail in NAVSEA Dwg SK-F-8697. The test procedure is as follows:

1. Disconnect all hoses from the condenser that may have been used for prior tests and prepare the condenser circulating-water system for normal operation.
2. If possible, start the condenser circulating-water pump and circulate water through the condenser for 1 hour.

**Table 254-2-5** CONDENSER TUBE HYDROSTATIC TEST EQUIPMENT

| Test Method 4 | |
|---|---|
| **Quantity** | **Equipment List** |
| 1 | Portable blower to ventilate the waterbox |
| 1 | Nylon bristle brush for cleaning tube ends |
| 1 | Hydrostatic test pump |
| Sufficient | Compressed air hose with necessary valves and fittings (to be used to blow dry tubes to be tested) |
| Sufficient | Special tube test plugs and fittings (NAVSEA Dwg SK-F-8697) |

3. Close the condenser main injection and overboard discharge valves and tag to prevent unauthorized opening. Open all waterbox drain valves and drain the circulating-water side of the condenser.
4. Remove the waterbox manhole plates and ventilate the waterbox using a portable blower.
5. Clean the tube sheets and the first 2 inches of each end of the tubes. Blow the tube sheets dry with compressed air. Clean the tubes with a clean rag and a nylon bristle brush.
6. Insert the charging plug assembly and the vent plug assembly into opposite ends of the tube, as shown on NAVSEA Dwg SK-F-8697.
7. Tighten the plugs in the tube according to instructions in NAVSEA Dwg SK-F-8697.
8. Connect a hydrostatic test pump to the charging valve and fill the condenser tube with water.
9. When a solid stream of water appears at the discharge of the vent valve, indicating that all air has been purged from the tubes, close the vent valve.
10. Start the hydrostatic test pump and pressurize the tube to 400 psig.
11. Close the charging valve and disconnect the hydrostatic test pump.
12. Inspect the tube sheets for evidence of leaks around the charging and vent plugs. If leaks are observed, reseal the plug assemblies and recharge the tube.
13. Record the gage pressure at 1-minute intervals for 5 minutes. If there is no change in pressure, consider the tube to be satisfactory.
14. If pressure drops, repeat step 10 through step 13 to establish that a leak is present.

**NOTE**

Neoprene seals tend to deteriorate with continued use. If numerous tubes are to be tested, numerous seals will be required for the hydrostatic test assembly.

15. After completing this test and plugging or replacing any failed tubes, perform test method 1, 2, or 3 to verify condenser tightness.

254-2.6.12.6 Method 5. This test is similar to method 4 except that nitrogen is used as the test fluid. Table 254-2-6 lists the equipment for this test. The tube testing equipment is similar to that used for the hydrostatic test but with some significant differences. NAVSHIPS Dwg 810-2258253 provides a thorough description of this equipment. The test procedure is as follows:

1. Perform step 1 through step 5 of method 4.

2. Insert the charging and blind plugs into opposite ends of the tube to be tested, as shown on NAVSHIPS Dwg 810-2258253.

3. Tighten the plugs according to the instructions on NAVSHIPS Dwg 810-2258253.

4. Place a nitrogen bottle next to the waterbox that has the charging plug inserted in its tube sheet.

5. Attach a pressure regulator to the nitrogen bottle outlet and a high-pressure hose to the regulator outlet.

6. Adjust the pressure regulator to an outlet pressure of 530 psig.

**WARNING**

**Stay clear of the charging and blind plugs when the condenser tube is under pressure. Do not bump or disturb the plugs when under pressure.**

7. Attach the high-pressure hose from the regulator outlet to the charging plug. Charge the tube to 500 to 530 psig by slowly opening the regulator outlet valve.

**NOTE**

The pressure regulator is set at 530 psig to compensate for the loss of nitrogen that occurs when the high-pressure hose is disconnected from the regulator outlet.

8. Apply a soap solution to the tube sheets around the charging and blind plugs and all fittings. Inspect the plugs for leaks. If leaks are found, reseal the plug assemblies and recharge the tube.

9. Observe the charging plug pressure gage for an indication of pressure drop. Check the gage at 5-minute intervals for 30 minutes.

10. If the pressure drops, retest the tube using new neoprene seals in the charging and blind plugs. Conduct at least two tests to establish that the tube is leaking and that leak rates are similar.

11. After any failed tubes have been plugged or replaced, test the condenser using method 1, 2, or 3 to confirm tightness.

254-2.6.12.7 Method 6. This method is used to detect tube-to-outer-tube-sheet joint leakage in double-tube-sheet ondensers. (For other tests, see the manufacturer’s technical manual). The test procedure is as follows:

1. Close the condenser main injection and overboard discharge valves and tag them to ensure they remain shut.

2. Drain the waterbox, remove the inspection covers, and ventilate thoroughly. Clean the outer tube sheet to permit close examination of the tube ends.

3. Attach a hydrostatic test pump to the double-tube-sheet void drain connection.

4. Fill the double-tube-sheet void with water of secondary system quality.

5. Plug or cap the vent from the void.

**CAUTION**

**In some designs the double-tube-sheet void space should not be pressurized unless the waterbox is installed. The waterbox bolting and flange provide additional strength. Consult the equipment technical manual for guidance on this point.**

6. Pressurize the double-tube-sheet space to 100 percent of submergence pressure or seawater system design pressure.

7. Dry the outer tube sheet and carefully inspect for leakage.

8. Reroll any leaky tube sheet joints and retest. Reflare inlet tube ends after rolling the tube joint. Limit each reroll to a 0.001- to 0.002-inch increase in inside diameter.

**Table 254-2-6** NITROGEN TEST RIG EQUIPMENT

| Test Method 5 | |
|---|---|
| **Quantity** | **Equipment List** |
| Sufficient | Compressed air hose with necessary valves and fittings (to be used to blow dry tubes to be tested) |
| Sufficient | Tubing with special fittings to be used to charge the tubes with nitrogen |
| 1 | Nitrogen gas pressure regulator to reduce gas-cylinder pressure to 530 psig |
| 1 | Relief valve set at 550 psig |
| 1 | Nylon bristle brush for cleaning ends |
| Sufficient | Special tube test plugs and fittings (NAVSEA Dwg 810-2258253) |
| 1 | Portable blower to ventilate the waterbox |

254-2.6.13 TYPES OF TUBE LEAKS. The most common cause of tube leaks is tube wall deterioration that starts at the seawater side and proceeds through the tube wall to the steamside. Leaks may also be caused by deterioration at the steamside of the tube wall, by defects at the joint between the tube sheet and tube, or by cracks in the tube wall. Properly manufactured tubes that meet Navy condenser tube specifications and have been correctly installed will not split or crack in normal service. Details of any tube splitting during installation or service shall be brought to NAVSEA's attention as soon as possible. Repairing cracked or split tubes generally requires retubing.

254-2.6.14 GALVANIC CORROSION. Dissimilar metals joined together and immersed in an electrolyte (a current-carrying liquid like seawater) form a galvanic cell. An electric current flows from one metal to the other through the electrolyte, with the junction of the two dissimilar metals completing the circuit. The metal from which the current is flowing (the anode) will tend to suffer accelerated corrosion, termed galvanic or electrolytic corrosion. The metal to which the current is flowing (the cathode) will tend to corrode at a slower rate.

254-2.6.14.1 Current Flow. The direction and rate of current flow depends on the composition of the two metals and also factors such as the hardness and cleanliness of the metal surfaces. If several different metals are involved, current will flow from the metal with the higher electron potential (more active) to that with the lower potential (less active). The rate of current flow (and thus the rate of galvanic corrosion) depends on the electron potential difference between the two metals. If a single metal is immersed in an electrolyte and one part of the metal surface is harder or cleaner than another part, current will flow between these parts and galvanic corrosion will occur.

254-2.6.14.2 Use of Zinc. If clean metallic zinc is attached to condenser or heat exchanger waterboxes, current will flow from the zinc to adjacent metal surfaces exposed to seawater since zinc is more active than the materials used in the condenser and heat exchanger. The zinc (anode) thus corrodes rather than the tubes, tube sheets, waterboxes and shells (cathodes). This is called cathodic protection. Gaskets between the manhole covers to which the zinc anodes are frequently attached and the waterboxes do not interrupt the current flow since the circuit is completed through the metal bolts and collar studs that secure the covers.

254-2.6.14.3 Cathodic Protection. Sacrificial anodes shall be installed in the seawater side of all shell-and-tube seawater-cooled condensers and heat exchangers, in accordance with MIL-A-19521, to provide corrosion protection, with the following exceptions:

a. All anode support plugs in submarine (nonreactor plant) heat exchangers are required to conform to NAVSEA Dwg 803-5959186.

b. For condensers and heat exchangers with titanium tubes, guidance on the use of sacrificial anodes will be provided on a case-by-case basis.

254-2.6.14.4 Attachment of Zinc Anodes. Where zinc protection is used, good metallic contact must exist between the zinc protectors and the metal of the condenser so that the electrical circuit will not be interrupted. Ship's force should use the method shown in Figure 254-2-6 when installing additional zinc.

254-2.6.14.5 Zinc Plates/Slabs. Zinc plates are generally mounted with the collar of the supporting stud welded to the waterbox, or by firmly setting the supporting stud into a boss on the waterbox. This boss or collar often contains sharp ridges, eliminating the need for a separate ridged washer on this side of the zinc. Always, however, use a ridged washer under the supporting nut on the opposite side of the zinc plate. Firmly make up the joint with the split pin in place to avoid the possibility of the zinc plate or supporting nut coming loose during operation and damaging the unit. A zinc slab arrangement used in more recently built ships is shown in Figure 254-2-7. This arrangement provides for mounting the plate on a boss (or bosses) and securing it on a 1/2-inch diameter stud (or studs) with two jamnuts per stud. The stud passes through a 1/2-inch iron pipe size (IPS) pipe inserted in the plate.

254-2.6.14.6 Zinc Pencils and Discs. Since small condensers or heat exchangers often have no manholes or handholes in their waterboxes, access to zinc anodes is difficult. In such cases, the zinc anodes are often installed as shown in Figure 254-2-8. This provides access for routine zinc replacement without the necessity for removing the waterbox.

254-2.6.14.6.1 In these installations a zinc pencil is used instead of a zinc plate. Size the zinc pencil and support plug as shown on the condenser or heat exchanger drawings. Make up the threaded joints securely to provide good metallic contact and to prevent the zinc pencil from becoming detached from the supporting plug and damaging the unit.

254-2.6.14.6.2 Some installations use zinc pencils with the same diameters as standard iron pipe. One end is threaded with a standard pipe die and the supporting plugs are tapped with similar threads. This saves work when preparing replacement zincs from bar stock. Segmented pencil-type zinc anodes have also been used. The segments may be requisitioned for replacement stock and the proper length pencils can be formed by screwing the segments together and into the supporting plug.

254-2.6.14.7 Care of Zincs. Periodically inspect condensers and heat exchangers that depend on zinc anodes for protection from galvanic corrosion to ensure that the protection is maintained. The proper inspection interval for a given piece of equipment is best determined by experience.

254-2.6.14.7.1 Before opening the seawater side of a condenser or other component to inspect zinc anodes, observe the precautions of paragraph 254-2.6.1. Remove accumulated dirt or seaweed from the zinc assemblies and examine them for a coating of hard scale. If such scale is present, use a wire brush or scraper to remove it and expose the bright metal surface.

254-2.6.14.7.2 The specification for zinc anodes (MIL-A-18001, Anodes, Corrosion Preventative, Zinc: Slab, Disc, and Rod Shaped ) calls for a grade of zinc that will remain active in a seawater environment without excessive scale formation. The grades of zinc formerly used for anodes were of lower purity. Low-purity grades tend to form hard adherent scales, which quickly reduces the protective action (current-generating ability) of the zinc. For such grades of zinc, chipping hammers and wire brushes are normally required to remove scale and restore the anodes to effectiveness.

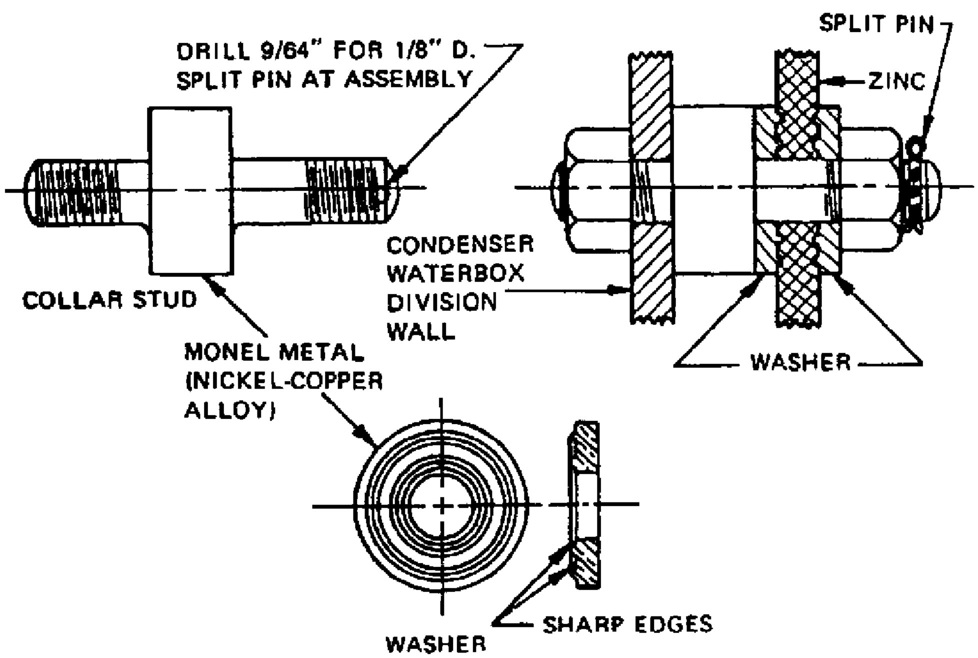



Figure 254-2-6. Plate-Type Zinc Anode Installation

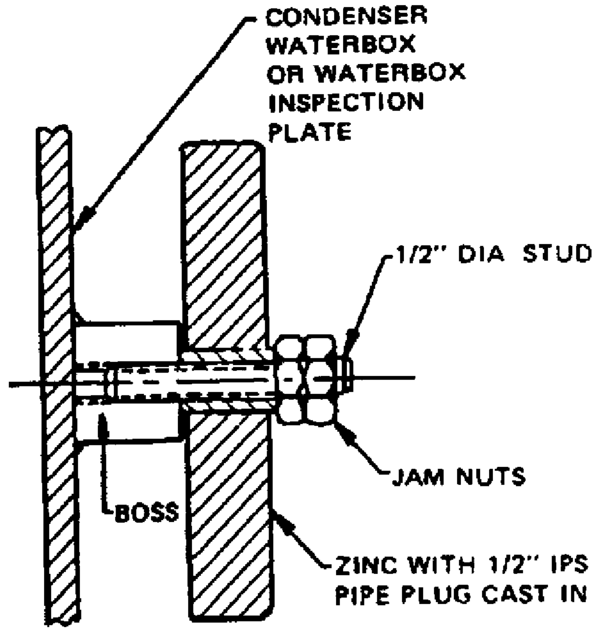



Figure 254-2-7. Zinc Slab Arrangement

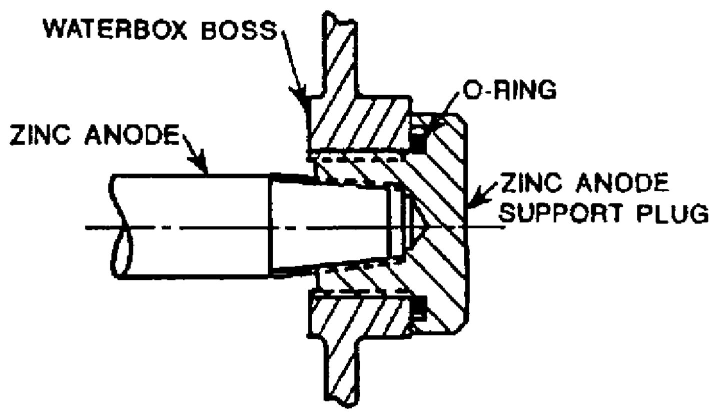



Figure 254-2-8. Pencil-Type Zinc Anode Installation

254-2.6.14.7.3 Whenever zincs are inspected, make sure they are tightly assembled to make good contact with each other (interlocking pencil coupons) and with supporting washers, bosses, and plugs, and to resist vibration. A complete electrical path back to the supporting waterbox wall is essential for proper cathodic protection.

**CAUTION**

**Do not lubricate anode mounting studs. Lubricating anode mounting studs will increase electrical resistance and inhibit cathodic protection.**

254-2.6.14.7.4 Functioning zincs will be steadily consumed (corroded) over all surfaces. Replace zincs when they are half deteriorated or if they show no deterioration after having been in service. Zincs that do not corrode in service are non-functional because they are of improper material or they have been improperly installed (loose or lubricated parts causing excessive electrical resistance). Non-functioning zincs will retain the shape of a new anode and may be covered with a hard, adherent, dark gray or black film. When reinstalling anodes, ensure that anode mounting studs are clean and unlubricated, that anodes are tightly assembled to anode mounting studs, and that access cover gaskets are renewed if damaged or deteriorated. Observe specific requirements for torquing fasteners and using locking devices.

254-2.6.15 SEAWATER EROSION/ CORROSION. Seawater flowing into condenser tubes at high velocity tends to remove the thin protective oxide film from the tube wall. This protective film is replaced by corrosion of the tube wall. As the removal and replacement of the protective film continues, the tube wall is gradually thinned and the joint between the tube and the tube sheet is weakened. Eventually a seawater leak can occur through failure of the joint or perforation of the tube wall beyond the tube sheet. This type of attack generally occurs in the tube inlet end and is termed impingement erosion, inlet end attack, air erosion, bubble attack, or erosion/corrosion.

254-2.6.15.1 New or Retubed Condensers. Copper-alloy tubes are particularly susceptible to erosion/corrosion when newly installed (such as during new construction or following retubing), before the protective oxide film has completely formed. Once new tubes or components have been exposed to seawater, maintain continuous seawater flow as long as practical to promote formation of the protective film.

254-2.6.15.2 Minimizing Erosion. The occurrence and rapidity of the attack depends mainly on the amount of circulating waterflow, the amounts of air and foreign matter in the water, and the design of the waterbox and injection piping. These affect the velocity, direction, and turbulence of the circulating waterflow approaching the tube ends. Regulate the circulating waterflow to the minimum required to maintain the desired vacuum for condensers (paragraphs 254-2.4.6 through 254-2.4.7.8) or to prevent heat exchanger overheating. This regulation and proper venting of the waterboxes will minimize tube end erosion damage. If temporarily installed equipment is used to provide seawater to copper-nickel tubes, ensure that the flow rate does not exceed that allowed during normal operation. This will prevent tube erosion/corrosion from excessive seawater velocity.

254-2.6.15.3 Air Venting. Most scoop-injected condensers have an air removal manifold that extends along the top of the inlet waterbox and encloses a row of holes through the waterbox body (Figure 254-2-1, view B-B). These holes allow about 1-1/2 percent of the circulating water to bypass the tubes. Entrained air rises to the top of the waterbox and passes through the holes to the overboard discharge piping or to the bilge (paragraph 254-2.4.7.4). Two-pass condensers generally have a row of air-venting holes through the inlet discharge waterbox division plate, near the tube sheet, for continuous air venting (Figure 254-2-3). The circulating waterflow rate also affects the amount of damage caused by entrained air since at slower flow rates a larger proportion of entrained air can be extracted by these venting devices, preventing the air from impinging on the tube ends.

254-2.6.15.4 Tube Inserts. Tube inserts, to prevent or arrest inlet end tube erosion, are generally not needed in Navy condensers. In some cases, however, tube inserts may be beneficial, particularly for ships operating in shallow, sandy bottom water. Plastic or nylon inserts, which are cemented in the tube ends, tend to back out of the tubes and crack or break. Metal inserts, which are roller-expanded into the tubes, are more durable and usually preferred over plastic or nylon inserts. If inlet end tube erosion is evident, consult NAVSEA to determine if tube inserts should be installed.

254-2.6.15.5 Division Plate Gaskets. Serious erosion of tubes and tube sheets in multiple-pass condensers and heat exchangers will result if the gasket between the waterbox division plate and the tube sheet is improperly installed or dislodges during operation. Examine heat exchangers and condensers for division plate gasket tightness whenever the waterboxes interiors are accessible.

254-2.6.15.6 Tube Sheets and Waterboxes. For steam condensers on superheated steam plant surface ships, erosion/corrosion damage to tube sheets and waterboxes may be repaired with epoxy using the guidelines in paragraph 254-2.6.32.

254-2.6.16 DEPOSIT ATTACK. Any foreign matter that lodges in a condenser tube can cause tube failure unless it is promptly removed. Barnacles, mud, scale, shells, stones, and wood lodged in the tubes can cause a corrosion pit to start at the tube surface under the foreign particles. Once the pit is well started, it may continue to deepen and widen even though the foreign material that started the corrosion is removed. In addition, the increase in local velocity and turbulence of the seawater flowing past the obstruction causes erosion of the tube's protective film. Tube failure occurs either at the contact area from deposit attack or downstream by corrosion/erosion.

254-2.6.17 DEZINCIFICATION. Dezincification may occur in seawater-cooled condensers and heat exchangers still using brass tubes. Dezincification of brass tubes is most likely to occur with hot, low-velocity seawater. Layer-type dezincification occurs over the entire tube surface exposed to the heated seawater and causes layers of porous, copper-colored scale that can be peeled off the surface. With very low water velocity, foreign particles may lodge on the tube surface and cause plug-type dezincification. This occurs when small plugs of porous copper form under the foreign particles and gradually perforate the tube wall.

254-2.6.17.1 Copper-nickel tubes are not subject to dezincification, but all types of corrosion attack generally proceed at an increased rate as the seawater temperature increases.

254-2.6.17.1.1 To minimize the deterioration of brass tubes through dezincification, take care, whenever practical, not to throttle flow to such an extent that the temperature of the seawater discharged overboard exceeds 130 degrees F for long periods of time. Also make sure that brass tubes are not plugged by kelp or other foreign matter at the inlet tube sheet since this may result in stagnant hot seawater in these tubes, particularly in lubricating oil and diesel engine freshwater coolers. This can cause rapid dezincification.

254-2.6.18 STRAY CURRENTS. Routine upkeep of the ship's electrical system (NSTM Chapter 300, Electric Plant - General) should prevent condenser tube corrosion from stray electric currents flowing through the ship's hull to the condensers and from there to the seawater, with subsequent tube corrosion and pitting (paragraph 254-2.6.14). Use return grounds during welding to minimize the possibility of condenser tube corrosion from stray welding currents.

254-2.6.19 STEAMSIDE EROSION. Wet steam striking the condenser tubes at a high velocity will rapidly erode the tube surface and perforate the tube wall, allowing seawater to leak into the condensate.

254-2.6.19.1 Impingement Baffles. Baffles and distribution pipes are installed in the condenser shell to prevent steam discharges from impinging on the tubes. This could occur in areas such as the auxiliary exhaust and steam dump lines, condensate recirculation and makeup feed lines, and turbine and high-pressure drain lines. Some condensers also use baffles under the turbine exhausts to prevent direct impingement on the tubes.

254-2.6.19.1.1 Inspect baffles and distribution pipes for damage and tightness wherever access to the steamside is provided for any purpose, and whenever it is suspected that a steamside baffle has dislodged or become perforated. For inspection requirements see paragraph 254-2.6.9.1. Baffles should not touch the tubes as vibration may cause tube failure. Frequent tube leaks near a steam or water connection to the condenser shell strongly indicate that baffles are defective or the plant is improperly operated. If the cause of tube erosion cannot be easily determined and corrected, plug the tubes.

**CAUTION**

**Clip-on stainless steel tube protectors can become dislodged from tubes and damage pumps. Tube protectors are for temporary use only until permanent modifications, such as welded-in baffles, can be installed.**

254-2.6.19.1.2 If the tube erosion area is accessible, it may be temporarily protected from further damage by installing clip-on stainless steel tube protectors (NSN 4730-00-517-7935 for 5/8-inch outside-diameter tubes) on all eroded tubes. These tube protectors should clip tightly onto the tube and cover the eroded area. However, because tube protectors cannot be secured to tubes, they can become dislodged and cause damage to downstream components. Tube protectors are for temporary use only until permanent modifications, such as welded-in baffles, can be installed.

**NOTE**

For steam condensers on saturated steam plant ships, contact NAVSEA 03Z43 before installing clip-on tube protectors.

254-2.6.19.2 Main Condensers with Pump Circulation. The main condensers for these installations are designed for a relatively high absolute pressure (4 to 8 inches of mercury absolute) when handling full-load exhaust steam from the turbines and receiving full-rated flow of circulating water at design temperature, typically 65 degrees or 75 degrees F. The traditional practice of operating at the best vacuum obtainable regardless of plant load, water temperature, and so forth, is not appropriate at reduced load for these condensers. Under such conditions the best vacuum obtainable may produce excessive steam velocities in the condenser, creating an erosion hazard to the tubes or shell structure from the relatively wet exhaust steam of the saturated plant.

254-2.6.19.2.1 The increase in steam velocity stems from the rapid increase in steam volume as the absolute pressure changes; for example, from 5 inches of mercury (the design point at full load) toward 2 inches of mercury or less (under the influence of reduced steam load, colder water, or both). Refer to a table of saturated steam properties to see how rapidly specific volume (ft3/lb) changes in the absolute pressure range from 2.5 to 1 inch of mercury and lower. For a given weight of steam flowing through the condenser, the velocity increases with specific volume.

254-2.6.19.2.2 For this type of main condenser, therefore, avoid the extremes of absolute pressure when a light- or medium-load condition, in combination with cold circulating water, is expected for any extended operating period. Always maintain absolute pressures greater than 2 inches of mercury, if possible. To do this reduce the seawater flow through the condensers by operating the circulating pumps at slow speed or by using one pump to supply both condensers. Other methods, such as throttling steam flow to the air ejectors or bleeding air into the condensers, could increase the dissolved oxygen content in the condensate and are prohibited.

254-2.6.19.2.3 For ships with auxiliary heat exchangers supplied from the main seawater circulating system, the condenser shall be operated such that lube oil temperature, generator cooling-air temperature, and gland exhaust condenser vacuum are consistent with the values given in the applicable instruction books for the equipment.

254-2.6.19.2.4 The seawater outlet temperature of any heat exchanger, including the main condenser, should not exceed 140°F. This is the only limitation on temperature rise across the seawater side of any heat exchanger.

254-2.6.19.2.5 When operating with one pump supplying two condensers, place the idle pump in operation immediately if there is a significant increase in condenser loading. This will prevent a possible loss of condenser vacuum.

254-2.6.19.3 Auxiliary Exhaust Dumping. To prevent tube erosion from auxiliary exhaust dumping lines, drain the lines thoroughly and continuously at all low points. Internal baffling systems will not prevent water (discharged at high velocity into the condenser) from bouncing off of baffles, tube sheets, support plates, or other internal shell structures and eventually impinging on the tubes with sufficient force to cause erosion.

254-2.6.19.3.1 If there are undrained pockets in the line ahead of the back-pressure valve where condensate can collect, install a drain well and connect it (through an automatic trap) to the freshwater drain collecting system. Make sure that the drain will provide positive and complete drainage under all operating conditions.

254-2.6.19.3.2 If there are undrained pockets between the back-pressure valve and condenser, install a drain line connecting the bottom of the pocket to a lower point on the condenser shell. Connect this line to the hot well if possible. If the drain line must be connected elsewhere, make sure that it does not directly impinge on any of the condenser tubes.

254-2.6.19.4 Condensate Recirculation. Baffles over the condenser shell water inlets are designed to protect the condenser and turbine from erosion when these inlets discharge normal quantities of water into the condenser. Do not admit unnecessarily large quantities of water to the condenser. This will ensure that these water inlet baffles are not overloaded. Guard against recirculating excessive amounts of water from the condensate system at points beyond the air ejectors. Properly set and functioning thermostatic recirculating valves will automatically recirculate the proper quantity of water for condensing steam in air ejector inter- and after-condensers.

254-2.6.19.4.1 If recirculation is normally controlled manually rather than thermostatically, install an orifice in the recirculating line about 3 feet from its connection to the condenser. This will limit recirculation to the minimum quantity of water necessary for properly operating air ejector and gland exhauster condensers. It will also promote plant economy and minimize the possibility of condenser tube or turbine erosion. If in doubt about the proper orifice size and location for a particular installation, consult NAVSEA.

254-2.6.19.4.2 Specifications now require two recirculating connections. The first, for use in start-up, is located so that recirculated condensate drips down over the tubes for cooling. The second, for use in normal operation, is located to ensure that the recirculated condensate does not impinge on adjacent tubes. Proper use of these two connections will help minimize erosion.

254-2.6.19.5 Main Steam Dumping. Main steam dumping permits increased flexibility in operating and testing some plants. Main steam dumping at high power for extended periods of time should be avoided, however, since such operation is stressful to the condenser and may increase the probability of leaks developing in the condenser tubes or of other structural failures.

254-2.6.20 AIR LEAKAGE TESTING. Inadequate vacuum may be caused by excessive air leakage into the condenser and connected equipment and piping (paragraph 254-2.4.2). For submarine condensers, excessive air leakage can be verified as the cause of substandard vacuum by conducting a vacuum drop test as discussed in the following paragraphs, provided the steam system and all supporting systems are operational. A similar test can be applied to surface ship condensers, but acceptance criteria for these units have not yet been established.

254-2.6.20.1 Condenser Vacuum Drop Test. The initial condenser vacuum must be greater than 25 inches of mercury before performing this test. Gland seal and exhaust systems must be operating, and turbines exhausting to the condenser being tested must be on jacking gear or spun unloaded by steam. To begin the test, secure the main air ejectors (but not the gland exhaust ejector) on the condenser to be tested. This is done by first closing the main air ejector suction valves and then securing the steam to the main air ejectors. Measure the time it takes for the vacuum to decay by 10 inches of rejection:mercury. The following are the criteria for acceptance or rejection:

a. If a vacuum drop of 10 inches of mercury takes more than 30 minutes the system is satisfactory.
b. If a vacuum drop of 10 inches of mercury takes between 25 and 30 minutes the system has minor leakage. Correct the leaks at the next overhaul to increase vacuum drop time to greater than 30 minutes.
c. If a vacuum drop of 10 inches of mercury takes less than 25 minutes the system is unsatisfactory. Locate and correct leaks immediately.

**NOTE**

Conduct the test during preoverhaul testing to determine condenser condition. Conduct the test again during shore-steaming operations to verify vacuum system tightness.

**CAUTION**

**With either test method given below, install a relief valve on each air supply line to the condenser. Set the relief valve to 105 + 2 percent of the test pressure.**

254-2.6.20.2 Air Leakage Locating Tests. Locate large air leaks in the vacuum system using a candle flame or smoke while the system is under vacuum. Locate smaller leaks by pressure-testing the condenser, turbine exhaust casing, and attached piping (normally under vacuum). This test may be conducted with the condenser shell either filled with water and pressurized with air or simply pressurized with air.

254-2.6.20.2.1 For the shell-filled air test, fill the steamside of the condenser with feedwater-quality water to cover the top row of tubes. Avoid flooding the turbine. Install clear plastic tubing to monitor the water level as outlined in paragraph 254-2.6.20.2.5. Apply air pressure up to 15 psig through the turbine casing or upper shell connection.

254-2.6.20.2.2 For the shell-empty air test, apply up to 15 psig of air pressure to the shell through a shell access cover plate that has been modified to accept air supply lines or through some other suitable connection.

254-2.6.20.2.3 With either air test, the shell air pressure will be limited by the quantity of air available to make up losses through the turbine glands. To minimize air leakage past the glands, pack clean rags into accessible openings at the glands and seal with pressure-sensitive adhesive tape. (Count the rags before and after use to ensure that none remain in the glands.) Be sure to inspect the entire vacuum system during this test. Check for water leakage from any parts of the system filled with water. Test parts not filled with water by applying a soap solution to all suspect areas while the system is under air pressure. Examine the following areas (common to most turbine-condenser installations) as far back as the vacuum could exist under any operating conditions:

a. Turbine exhaust flanges, expansion joints, and turbine exhaust casing inspection openings and bolted connections.
b. Condenser shell inspection openings.
c. Vacuum gage and overpressure trip lines.
d. Thermometer connections.
e. Air ejector suction lines back to air ejectors.
f. Makeup feed line.
g. Steam dump and or auxiliary exhaust lines.
h. Distilling plant and air-conditioning plant drain lines.
i. Drain collecting system drain line.
j. Turbine drain lines.
k. Air ejector intercondenser drain line.
l. Condensate and feed pump recirculating lines.
m. Condensate pump suction and vent lines.
n. Hot well gage glass and fittings.
o. Hot well drain connections and inspection openings.

254-2.6.20.2.4 Small leaks at flanged joints and porous castings can usually be temporarily corrected by wrapping the joints with flexible plastic wrap while the system is under vacuum or by marking leaking areas and applying several coats of shellac to those areas after vacuum has been broken. Leaks in valves and other components require disassembly for repair. Main exhaust trunk flanges generally have a flange-grooving system in cases where the condenser supports the turbine. This allows pressure pumping of a suitable sealing compound. Most shell relief valves have a small gage glass to permit introducing water above the valve disk as a tightness test.

254-2.6.20.2.5 For double-tube-sheet condensers, use the following additional tests to detect air leaks:

a. Test for air leaking past loose tube-to-tube-sheet joints in the inner tube sheet with vacuum on the condenser as follows:
   1 Plug or cap the drain from the space between the double tube sheets.

2 Install a vacuum gage on the vent from this space. Air leakage will be indicated by an increase in vacuum in the space.

b. Locate loose tube-to-inner-tube-sheet joints with the condenser operating as follows:

1 Attach a T-pipe fitting, containing a vacuum gage and petcock, to the vent line from the space between the inner and outer tube sheets.

2 Connect a valve to the drain line from the space between the double tube sheets and connect a clear plastic hose from this valve to a suitable source of freshwater.

3 Make sure that these fittings contain no leaks.

4 Admit water to the space between the double tube sheets a little at a time.

5 Break the vacuum between the double tube sheets, after admitting a small amount of water, using the petcock installed in the tee (step 1). Close the petcock and time the vacuum increase.

6 Time the vacuum increases after adding additional small amounts of water. When the leaking tube-to-tube-sheet joint is covered with water, the time required to obtain vacuum in this space will increase.

7 Determine the water level in the double tube sheet space, using the clear plastic hose as a gage glass, after the leak is covered.

8 Roll all the tubes in the inner and outer tube sheet just below the water level where the leak was detected. (Rerolling the inner tube-to-tube-sheet joints causes the tube to grow slightly. This could loosen the rolled outer tube-to-tube-sheet joint, requiring rerolling. Outer-tube- to-tube-sheet joints may be rolled, however, without rerolling inner tube-to-tube-sheet joints. In both cases, inlet tube ends must be reflared.)

c. Locate loose tube-to-inner-tube-sheet joints with the condenser secured as follows:

1 Attach to the double-tube-sheet vent connection a T-pipe fitting containing, on one end, a pressure gage and, on the other end, another tee with two 3/4-inch hose fittings.

2 Attach a T-pipe fitting with two 3/4-inch hose fittings to the double-tube-sheet drain.

3 Attach a length of 3/4-inch clear plastic hose between the T-fittings in the double-tube-sheet vent and drain. This hose will be used as a gage glass.

4 Attach a 3/4-inch hose from a freshwater source in the ship to the T-fitting in the double-tube-sheet drain. Attach an air hose from the ship's low-pressure air system to the fittings in the double-tube-sheet vent.

5 Apply 30 psig of air pressure to the space between the double tube sheets. Be sure that all added connections are tight.

6 Add water to the double-tube-sheet space in 3-inch increments. Time the pressure drop after each addition of water. When water covers the leak, the rate of pressure drop will decrease. At this point, reroll all tubes in the inner and outer tube sheets just below the indicated water level.

254-2.6.21 WATERBOXES. Condenser and heat exchanger waterboxes of copper-nickel, aluminum bronze, valve bronze, or gun metal normally require little maintenance. The interior surface, however, requires periodic cleaning as noted in paragraph 254-2.6.5 to avoid pitting under marine growth. Maintain other waterboxes as follows.

254-2.6.21.1 Monel Waterboxes. Many main condensers have Monel (nickel-copper alloy) waterboxes. The interior surface is coated with solder that is two-thirds lead and one-third tin to prevent galvanic corrosion between the bare Monel surface and the tubes and tube sheet. Take care not to damage manufacturer-applied coating during other work. The solder coating should not be repaired, primarily due to the toxic nature of the materials involved (lead and tin) when heated or when abraded such as by grinding or grit basting.

**NOTE**

The solder coating assists the installed zinc anodes in preventing galvanic corrosion of the tubes and tubesheet. It is very important that installed zinc anodes be carefully maintained, and replaced when they are half deteriorated or if they show no deterioration after having been in service. Refer to 254-2.6.14.7.

254-2.6.21.2 Steel and Cast Iron Waterboxes. For cast iron or steel waterboxes that have not been given an initial protective coating on the seawater side, thoroughly clean the interior surfaces, preferably by abrasive blasting. When this is impractical, remove dirt by wire brushing, sanding, or other suitable mechanical means, followed by solvent cleaning.

254-2.6.21.2.1 After surface preparation, apply a tank coating system qualified under MIL-P-23236, Paint Coating Systems, Fuel and Salt Water Ballast Tanks (Metric), (class 1, 2, or 4) as prescribed in NSTM Chapter 631, Volume 2, Preservation of Ships in Service (Surface Preparation and Painting). Record the specific coating used on the appropriate machinery history cards.

254-2.6.21.2.2 Inspect the protective coating on iron or steel waterboxes at each overhaul. Repair deteriorated areas in accordance with NSTM Chapter 631. Formerly, these boxes were coated with Portland cement. If cement coatings have begun to deteriorate, replace them as described in paragraph 254-2.6.21.2.1.

**WARNING**

**The materials used in this procedure may produce hazardous vapors, may be flammable, or both. Always provide sufficient ventilation, keep all containers closed when not in use, and ensure that the material is not applied to hot surfaces or near open flames.**

254-2.6.21.3 Rubber-Lined Waterboxes. Steel waterboxes on certain ship classes were originally lined with neoprene rubber to protect them from corrosion. Rubber linings should be inspected for damage or deterioration in accordance with PMS requirements. Rubber linings should be repaired as described in the following paragraphs, or replaced with an epoxy coating using the guidelines in paragraph 254-2.6.32.

254-2.6.21.3.1 Sources of the materials required for this repair procedure are as follows:

a. East Coast. Gates Engineering Co., Inc., 100 South West St., P.O. Box 1711, Wilmington, DE 19899.

b. West Coast. GACO Western, Inc., P.O. Box 88698, Seattle, WA 98188.

254-2.6.21.3.2 Materials required for a 20-square-foot repair, 1/16-inch thick are:

a. Trowelling Compound N-250, 10 pound.

b. Trowelling Compound Accelerator A-5, 1-1/4 ounce per pound.

c. Accelerator A-5 for putty form, 1 ounce per pound.

d. Neoprene Cement N-29, 1 gallon.

e. Neoprene Cement Accelerator N-39, 8 ounces per gallon.

f. Primer N-11, 1 gallon.

g. Cleaner and Thinner N-450-9, 1-1/2 gallon.

254-2.6.21.3.3 Repair neoprene rubber linings as described in the following steps:

1. Surface preparation. Cut out the damaged or blistered area of the neoprene lining. Lightly roughen this area with a small grinding wheel or sandpaper and clean the metal free of old primer, rust, dust, and foreign matter. Wipe damaged areas with a rag dampened with Cleaner and Thinner N-450-9.

2. Priming. Apply two brush coats of Primer N-11 to the exposed metal only. Do not apply primer to surrounding neoprene lining. Allow 30 minutes drying time between primer coats and after the last coat.

3. Adhesive. Thoroughly mix Neoprene Cement N-29 with Accelerator N-39. The mixing ratio is 1 gallon N-29 to 8 ounces N-39. Shake or stir the N-39 before mixing. Apply two brush coats to the primed area and over the neoprene lining, covering a 1-1/2 inch margin around the damaged area. Allow 30 minutes drying time between adhesive coats and after the last coat.

4. Neoprene putty. If there are abnormal pits in the surface to be covered or if sharp corners or grooves require filleting, use Trowelling Compound N-250 in a putty form. The putty is made by thoroughly mixing 1 ounce of Accelerator A-5 with each pound of Trowelling Compound N-250. Apply the mixture (putty) with a putty knife. Bevel edges of putty to 45 degrees (Figure 254-2-9).

5. Neoprene Trowelling Compound. Thoroughly mix Trowelling Compound N-250 and Accelerator A-5 in the ratio of 1-1/4 ounces of A-5 per pound of N-250. A suggested method is to mix the N-250 and A-5 on a glass or porcelain sheet with a putty knife or spatula. Immerse the mixed material in a pan of denatured alcohol to prolong stability and make it easier to apply. The trowelling compound is a thick, heavy material and may be efficiently mixed and applied with the hands. If mixing or applying the material by hand, however, wear rubber or plastic protective gloves. Keep hands and tools wet with alcohol or Putty Vehicle N-450-2 when applying the material since it is tacky and will stick to dry hands or tools. Apply the required thickness of trowelling compound to the prepared surface after completing step 1 through step 4 (Figure 254-2-9). Apply the compound not more than 1/16-inch thick at a time to avoid trapping air. Allow at least 1-hour drying time before immersion.

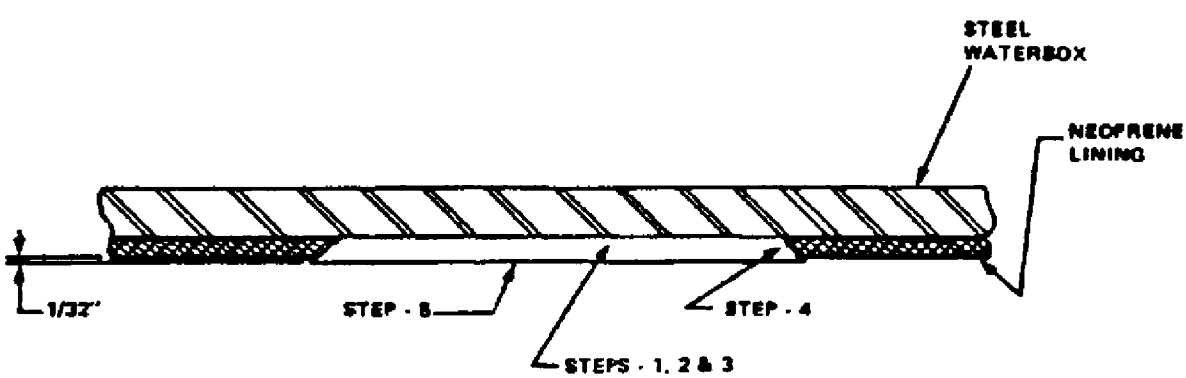



Figure 254-2-9. Waterbox Rubber Lining Repair

254-2.6.22 SPECIMEN TUBE INSPECTION. Occasionally it is necessary to remove and inspect tubes to help determine the cause of a problem in the condenser. Tube specimens should be removed only under the following conditions:

a. If frequent leaks have been caused by tube failures. Draw specimen tubes from widely separated parts of the unit to establish the general condition of tubes.
b. If several tubes have failed near a steam or water inlet to the condenser shell. Draw specimen tubes unless the cause of the failure can be determined by visual inspection of steamside.
c. If eddy current inspections indicate problems.
d. When directed by NAVSEA.

254-2.6.22.1 Advise NAVSEA of the existence of the conditions described in paragraph 254-2.6.22. Forward the following information:

a. The condenser involved and the last date it was tubed or retubed.
b. Whether tube leaks were caused by improperly expanded or packed tube joints.
c. The date each leak occurred, the type of tube failure (usually determined when the failed tube is drawn and split for inspection), and known or suspected contributory causes.
d. The position in the tube bundle of each failed tube and of each specimen tube drawn for inspection.
e. In what part of each specimen tube the defects were found: external, internal, top, bottom, sides, or location along its length. (Mark the tube ends before removal so the top can be located.)
f. If zinc or iron anodes were installed.

**NOTE**

If severe deterioration of the tube ends and tube sheets is visible and photographic equipment is available, take photographs of the tube sheets and forward them to NAVSEA.

254-2.6.22.2 Carefully mark samples from badly deteriorated tubes to show the location from which they were drawn and the top and bottom of the sample. Cut these samples in lengths of about 12 inches and identify their positions along the tube length. Split them lengthwise and open to permit ready examination. Forward the samples to NAVSEA so that the required data will be available if needed. Keep a service history sheet for each condenser. If tube leaks are discovered in the main or auxiliary condensers for any nuclear ship, report this to NAVSEA, who will determine if additional investigation is needed.

254-2.6.23 TUBE REPLACEMENT. Replace plugged tubes whenever the number of plugged tubes in a condenser or heat exchanger approaches 10 percent of the total. At that point, the effect of the plugged tubes on the operation of the unit should become noticeable.

254-2.6.23.1 Authorization. Obtain NAVSEA authorization before completely retubing a main propulsion condenser. Furnish the following information with the request for such retubing:

a. Data required by paragraph 254-2.6.22.1.

b. Recommendation and comment by superior authority endorsing the request for retubing.

254-2.6.23.1.1 Completely retubing auxiliary condensers or other types of heat exchangers and replacing individual tubes in main propulsion condensers may be done by tender or shipyard personnel, when necessary, without obtaining prior NAVSEA approval. Send supplemental information and recommendations to NAVSEA in cases where the tube conditions (such as steam erosion) indicate a need for design modification, where the actual construction varies from applicable drawings, or where any other unusual conditions exist.

254-2.6.23.2 Complete Retubing. When completely retubing single-tube-sheet units, the old tubes may be cut inside the shell with a power-driven saw and the ends driven out of the tube sheets with a drift pin. A suitable drift pin for a 5/8-inch outside-diameter tube having a wall thickness of 0.049 inch is shown in Figure 254-2-10. When tubes are expanded only at the inlet ends or are packed at both ends, the best removal method is to drift the tubes out of the condenser from the outlet end without cutting the tubes inside the condenser shell.

254-2.6.23.2.1 If expanded tubes are difficult to remove, it may be necessary to ream the expanded ends so that only a thin shell remains at the outer surface of the tube. Make sure that the reamer has a pilot that closely fits the inside diameter of the tube. Also make sure that the reamer does not cut through the tube wall and damage the tube hole in the tube sheet.

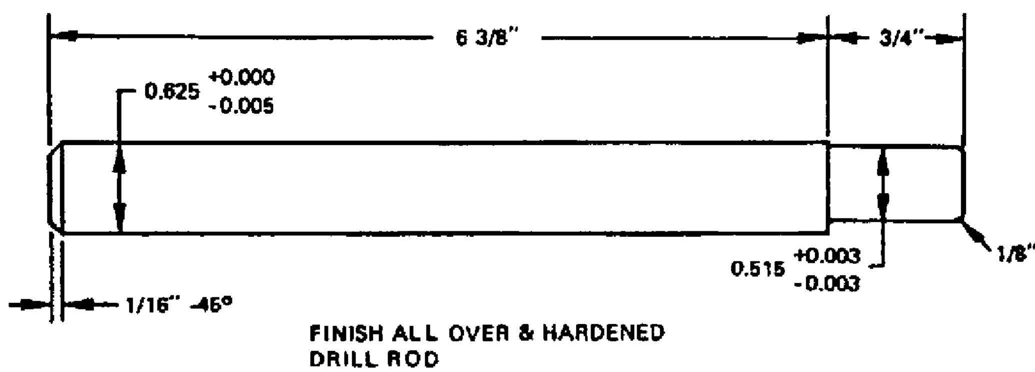



Figure 254-2-10. Tube Removal Drift Pin

254-2.6.23.2.2 Remove tubes carefully to avoid damaging the tube holes since successful expansion of the replacement tubes in the tube holes will require smooth surfaces. If the holes are scratched, grooved, burred, or otherwise damaged during tube removal, remove the defects by reaming. The diameter of the repaired hole shall not, however, exceed those shown in Table 254-2-7.

254-2.6.23.2.3 Make sure that all the interior parts of the condenser shell (such as stay rods, hot well, internal baffles, and joints) are thoroughly inspected before installing replacement tubes. If there is any doubt whether the joints between the tube sheet and the condenser shell are in perfect condition, remove the tube sheets and regasket the joints. If the tube holes in the tube support plates are larger than specified in the condenser drawings, take corrective action to avoid problems due to tube vibration. If any serious internal defects are discovered after retubing, it may be necessary to cut out the newly installed tubes to make repairs, involving a great waste of material and time.

**Table 254-2-7** MAXIMUM TUBE HOLE DIAMETERS

| Nominal Hole Diameter (Inch) | Maximum Allowable Diameter (Inch) |
|---|---|
| 3/4 | 0.780 |
| 5/8 | 0.650 |
| 3/8 | 0.395 |
| 1/4 | 0.265 |

254-2.6.23.3 Tube Material. When condensers must be retubed, consult the equipment drawings or technical manual for the proper material and tube procurement specification. Condensers with copper-nickel tubes shall be retubed with tubes conforming to MIL-T-15005, Tube, 70-30 and 90-10 Copper-Nickel Alloy, Condenser and Heat Exchanger. Unless otherwise specified on the condenser drawing, use composition 90-10 for surface ships and composition 70-30 for submarines. Tubes that comply with these specifications are properly annealed during manufacture. Under no circumstances shall tubes or tube ends be annealed by any naval activity before installation.

254-2.6.23.4 Tube Length. Condenser tubes are generally furnished in stock lengths and must be cut to the proper length by the installing activity. Cut the tubes about 1/8 inch longer than the distance between the outside faces of the tube sheets. Finish them to the exact length required with an air-driven end mill or surface grinder after installation.

254-2.6.23.5 Tube Insertion. After completely removing the old tubes, inserting the new ones is easiest if personnel inside the condenser guide the ends of the tubes through the proper holes in the support plates and tube sheet. If space is restricted at the tube insertion end of the condenser, it may be faster to remove the tube sheet and replace it after all the tubes have been inserted. (The tubes may then be guided into the tube holes in the replaced tube sheet.) The unit will then be ready for expanding or packing the tube ends.

254-2.6.23.6 Individual Tube Removal and Replacement. Replacing individual plugged tubes with new tubes is laborious and tedious and should not normally be attempted. If it is necessary to replace individual tubes, some means must be provided for guiding the new tubes through the tube support plates. This is particularly true with curved or bowed tubes. The following paragraphs contain procedures for removing and replacing individual tubes.

**NOTE**

When individual tubes are removed and not replaced in double-tube-sheet condensers, use standard tube sheet plugs in accordance with NAVSEA Dwg 803-5959309 to plug tube sheet holes. This drawing is applicable to all double-tube-sheet condensers that have copper-nickel (70-30 or 90-10 alloy) tubes of 5/8-inch outside diameter and 0.049- or 0.065-inch wall thickness.

254-2.6.23.6.1 The following procedure (using the old tube to guide the new tube into place) is an acceptable method for both straight and curved tubes on single-tube-sheet condensers.

1. If the outlet end is packed, remove the tube packing with tools similar to those shown in Figure 254-2-11 and

Figure 254-2-12. With expanded tubes, cut the outlet end of the tube off flush with the outer face of the tube sheet. The inlet end of the tube may be reamed, as discussed in paragraph 254-2.6.23.2.1 if removal is difficult.

2. With a drift pin similar to that shown in Figure 254-2-13, start driving out the old tube. Do not drive the tube completely out of the tube sheet. The drift pin is designed to prevent this.

**CAUTION**

**Ensure that the tube removal adapter does not fall into the tube bundle, as it will be difficult to retrieve and may cause subsequent tube damage if left in the condenser.**

3. Withdraw the drift pin from the old tube and insert an adapter similar to that shown in Figure 254-2-14. Slip the end of the new tube over the other end of the adapter. Then guide the new tube into place as the old one is forced out. It is best to use three people for this job: two to push in the new tube and one at the other end to rotate the old tube. The latter person must not pull the old tube since it may come off the adapter. Likewise, the new tube must not be pulled back or it may come off the adapter. The adapter may be held securely to the new tube by installing an eyelet in one end of the adapter. Run a cable from the eyelet through the new tube and keep it pulled tight during installation. If the space at the removal end is less than the full tube length, bend the old tube back on itself or cut it into short lengths as it comes out.

4. A tube may be so badly corroded that it tends to kink, either while being started or later when being removed. Take care to prevent this since a badly kinked tube may block the removal of adjacent tubes. If a tube does not move at both ends at the same time or becomes difficult to move while being pushed out, discontinue removal, cut the old and new tubes flush with the tube sheets, expand the tube ends into the tube sheets, and plug the tube ends. If the condenser outlet tube ends are packed, plug the outlet end in accordance with paragraph 254-2.6.27.

254-2.6.23.6.2 Straight tubes will usually fit over a rod about 3/8 inch in diameter. Push the rod through the old tube, and then draw out the old tube, leaving the rod in place. The new tube can then be threaded into the condenser over the rod.

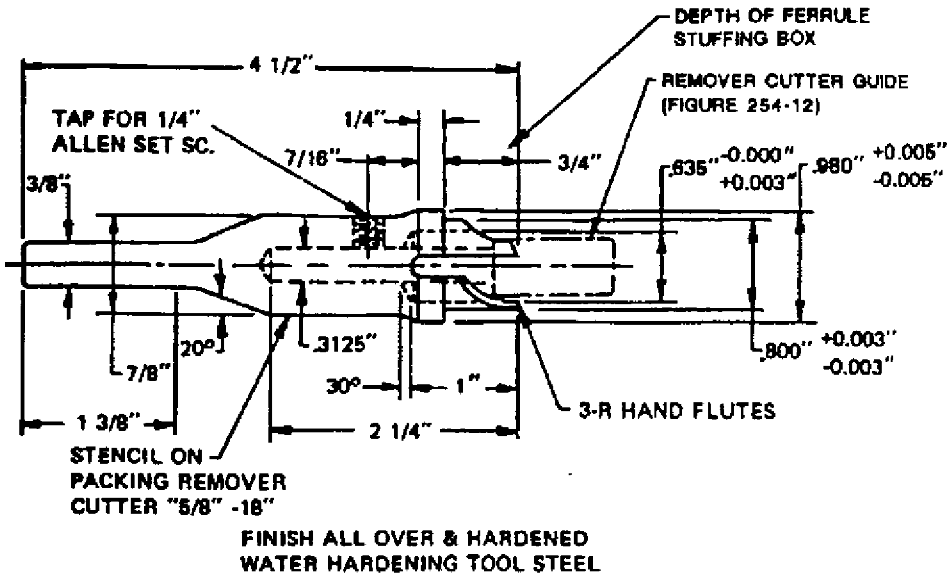



Figure 254-2-11. Tube Packing Remover

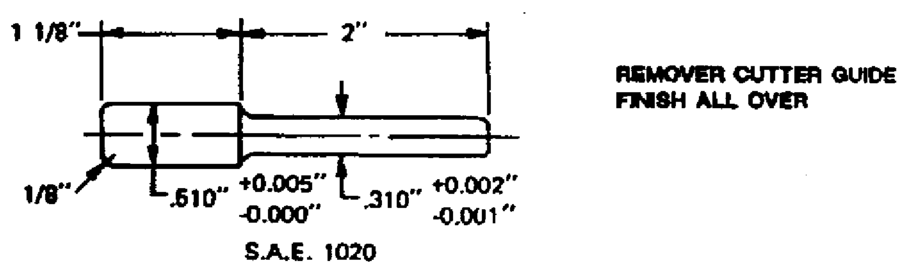



Figure 254-2-12. Cutter Guide for Tube Packing Remover

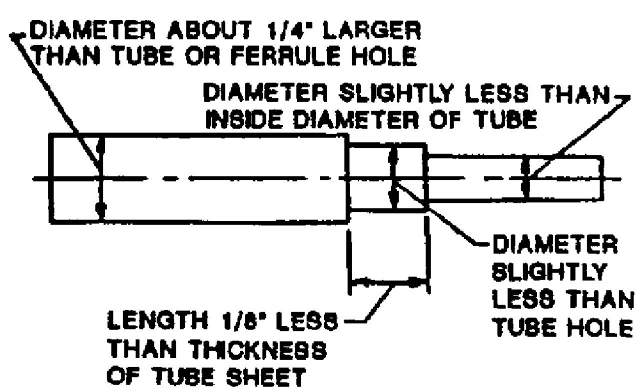



Figure 254-2-13. Tube-Starting Drift Pin

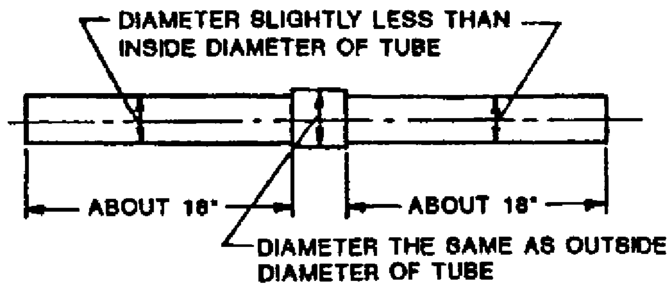



Figure 254-2-14. Tube Removal Adapter

254-2.6.23.6.3 The following procedure is suggested for removing individual tubes from double-tube-sheet condensers. It is applicable to all double-tube-sheet condensers with 5/8-inch outside-diameter tubes.

1. Provide a compressed air source (80 to 100 psig) for driving pneumatic equipment and blowing tubes clean. The equipment used for tube removal includes:
   a Pulling Spear. Boilermaker Tools Company Number TPD 625-16-18 or equal.
   b Pneumatic Drill. Reversible with Number 1 Morse taper drive, Thomas C. Wilson Model Number 930-450 or equal.
   c Internal Tube Cutter. A tube cutter for tubes with a 0.049-inch wall thickness is shown in Figure 254-2-15. For tubes with a 0.065-inch wall thickness, reduce the shaft diameter of the cutter, piece 3, from 0.500 to 0.475 inch. Reduce the internal diameter of the stop collar, piece 4, from 0.515 to 0.490 inch. If the total distance between the outer face of the outer tube sheet and the steamside of the inner tube sheet exceeds 6 inches, the lengths of the shaft, piece 3, and the plunger, piece 2, will need to be increased accordingly to allow cutting the tube approximately 1/2 inch beyond the steamside of the inner tube sheet, as described in step 2. The material for pieces 1 through 4 must conform to MIL-S-1222, B16,Studs, Bolts, Hex Cap Screws, Socket Head Cap Screws and Nuts.
   d Internal Tube Cutter Blades. Thomas C. Wilson Part Number 25186 or equal.
   e Internal Tube Cutter Blade Pins. Thomas C. Wilson Part Number 25171 for 0.049-inch wall tubes or Number 21570 for 0.065-inch wall tubes or equal.
   f Hollow Ram Hydraulic Jack. Airetool Model HDP-31, Enerpac Model Number HP20 or equal.
   g External Tube Cutter or Hacksaw.

**NOTE**

Equipment items a through fare on the Shore Intermediate Maintenance Activity (SIMA) shop survey equipment list and should be available at SIMA shops.

2. Set up the tube-removal equipment by adjusting the internal tube cutter reach with the stop collar provided. Set the stop collar to extend the reach of the cutter to approximately 1/2 inch beyond the steamside of the inner tube sheet. Adjust the cutter blade depth with the locknut provided. Set the depth to cut three-fourths of the way through the tube wall. Test the adjustments on a sample tube 12 inches long and of the same material, outer diameter (od), and gage as the tube to be removed.

3. Tap both ends of the tube with the tube pulling spear by threading the spear into the tube until firm resistance is met (7 to 10 turns). A reversible pneumatic drill may be used for threading. Remove the spear and air-lance the tube after tapping.

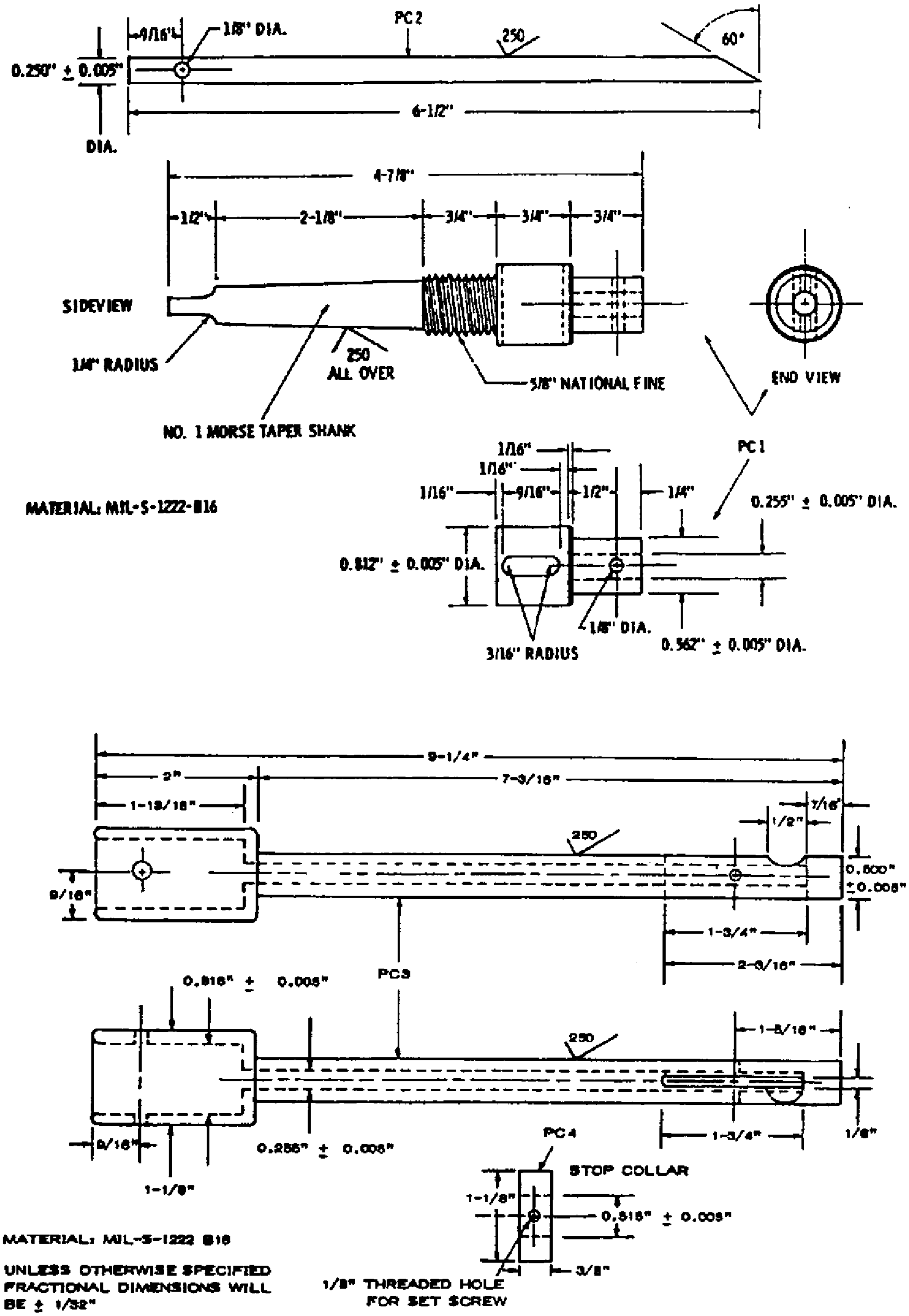



Figure 254-2-15. Internal Tube Cutter

**NOTE**

Use a suitable cutting oil during threading.

4. Determine the end of the condenser from which the tube will be removed.

**NOTE**

For submarine main condensers, tubes are normally pulled from the return waterhead end (assuming the inlet-outlet waterhead has not been removed).

5. Cut the tube end opposite the pulling end, using the internal tube cutter set as noted in step 2 Air-lance the tube to remove chips.
6. Thread the tube-pulling spear into the end of the tube cut in step 5.
7. Place the hollow ram hydraulic jack on the pulling spear. Attach the hollow ram hydraulic jack to the pulling spear using a horseshoe lock or nut, as applicable to the type of jack being used, to hold the hydraulic jack securely in position on the pulling spear.

**NOTE**

Place a 1/2-inch thick, 4-inch diameter sheet of rubber between the tube sheet and the hydraulic jack to protect the tube ends.

8. Operate the hydraulic jack through its full stroke then relieve the pressure.
9. Hit the hollow hydraulic jack on the horseshoe lock or nut, using it as a slide hammer to jar the tube loose and completely out of the tube sheet(s).
10. Thread the tube-pulling spear into the opposite end of tube (tube removal end).
11. Repeat step 7, step 8, and step 9 for the inlet end.

**NOTE**

To avoid stretching the tube, do not use the hydraulic jack to pull the tube again unless the slide hammer will not move the tube.

**CAUTION**

**If a tube being removed for analysis has to be cut in sections, the location of the cut(s) must be verified by a QA inspector so the tube can be correctly marked and tube portions to be analyzed will not be damaged.**

12. If the entire length of tube can be removed from the inlet end of the condenser without damage, do so. If the condenser waterhead is installed or if there is insufficient space to remove the entire tube, the tube may be cut into sections using an external tube cutter or hacksaw as it is pulled (see CAUTION above).

254-2.6.23.6.4 For tubes with a 0.049-inch wall thickness that are not readily removed using the procedure in paragraph 254-2.6.23.6.3, modify the procedure by substituting the following for step 3, step 6 and step 10.

a. For step 3, tap both ends of the tube with the 9/16-inch NF starting (taper) tap shown in Figure 254-2-16. The length of thread on each end of the tube should be 1-1/2 inches. Next, tap both ends of the tube with the 9/16-inch NF long-reach tap shown in Figure 254-2-17, extending the thread to the steamside of the inner tube sheet.

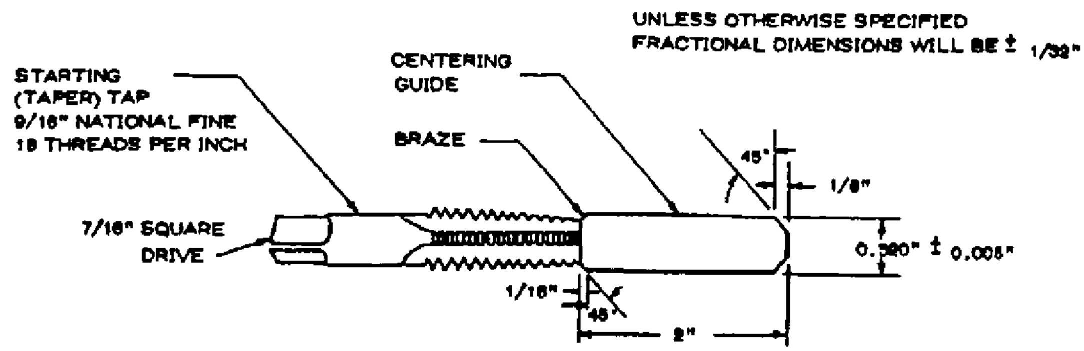



Figure 254-2-16. Starting (Taper) Tap

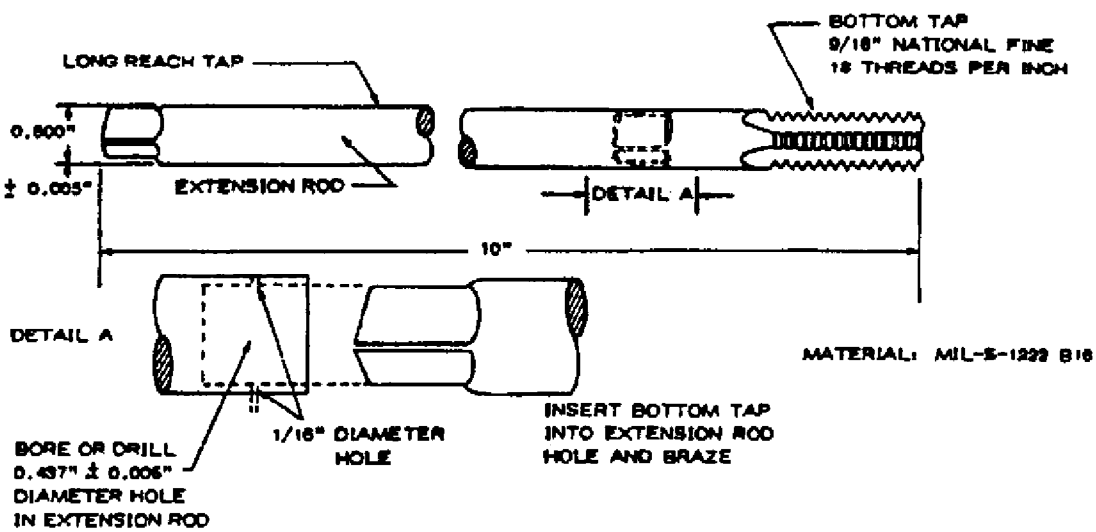



Figure 254-2-17. Long-Reach Tap

b. For step 6, install the tube puller (Figure 254-2-18) in the end of the tube cut in step 5.

c. For step 10, install the tube puller (Figure 254-2-18) in the opposite end of the tube (tube removal end).

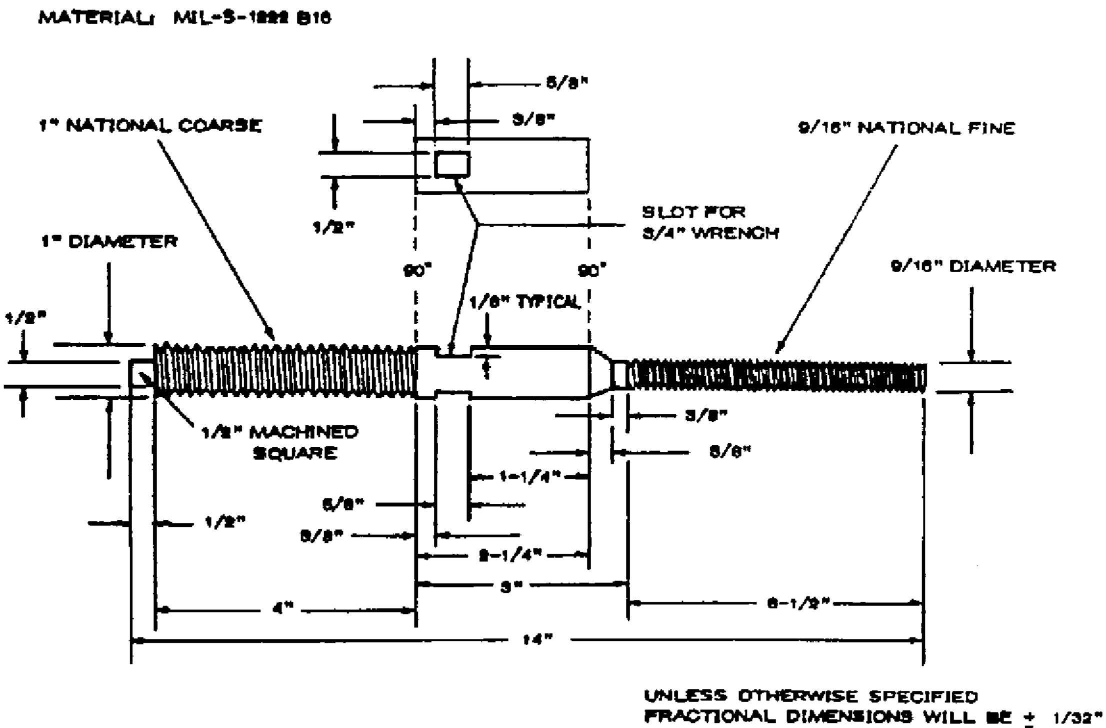



Figure 254-2-18. Tube Puller.

d. Use MIL-S-1222 B16 material for the taps and tube puller shown in Figure 254-2-16, Figure 254-2-17, and Figure 254-2-18.

254-2.6.24 EXPANDED TUBE JOINTS. Nearly all naval condensers have inlet condenser tube ends expanded into holes in the tube sheet, forming a metal-to-metal joint. In many installations, outlet tube ends are also expanded. If condenser tubes are expanded at both ends, the tube holes usually have one or more grooves or serrations to increase the holding power of the expanded tube joint. Before installing new tubes in such tube holes, thoroughly clean out and remove the burrs from the grooves.

254-2.6.24.1 Tube Expanders. Unless otherwise approved by NAVSEA or specified in the applicable component technical manual, tube expanders used for retubing shall conform to MIL-E-15809, Expander, Tube, Condenser and Heat Exchanger. No other type of tube expander should be used by forces afloat or naval shipyards for expanding tube joints in condensers and heat exchangers. Expanders furnished to the ship by the condenser manufacturer are, however, acceptable. Make sure that the expander rolls and the expander mandrel have the same taper for parallel expansion of the tube wall. The inner end of the rolls should be suitably rounded off to form a torpedo shape to prevent ridging and cutting of the tubes at the inner end of the expanded joint. For the tube expander to be properly suited for a given job, the rolls should be at least 3/16 inch longer than the thickness of the tube sheet into which the tube is expanded. Adjust the expander so that the expanded portion of the tube does not extend completely through the tube sheet. About 1/8 inch of the tube at the inner end of the tube hole should remain unexpanded. If tubes are expanded completely through the tube sheet, the part of the expanded joint that extends beyond the tube sheet will bulge and removing the tube will be extremely difficult. See Figure 254-2-19.

254-2.6.24.2 Tube Expander Controls. When expanding new tubes, use automatic tube expander controls to ensure correct tube expansion. These controls are available from tenders, repair ships, and naval shipyards. Private shipyards should also use automatic controls when retubing naval equipment. When rerolling tubes, manual operation of the tube expander may provide better control.

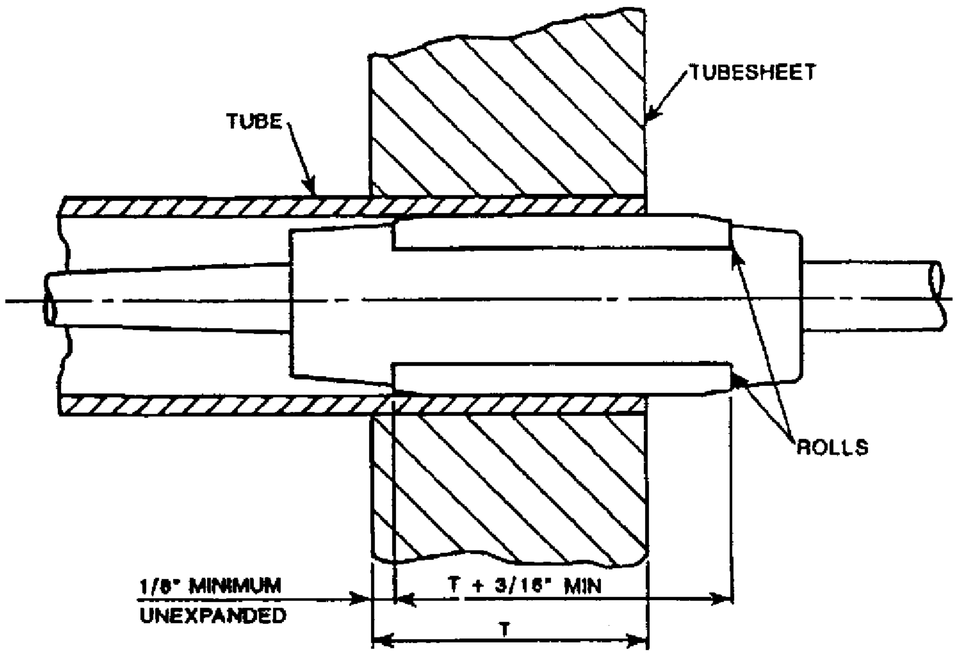



Figure 254-2-19. Tube Expander Adjustment

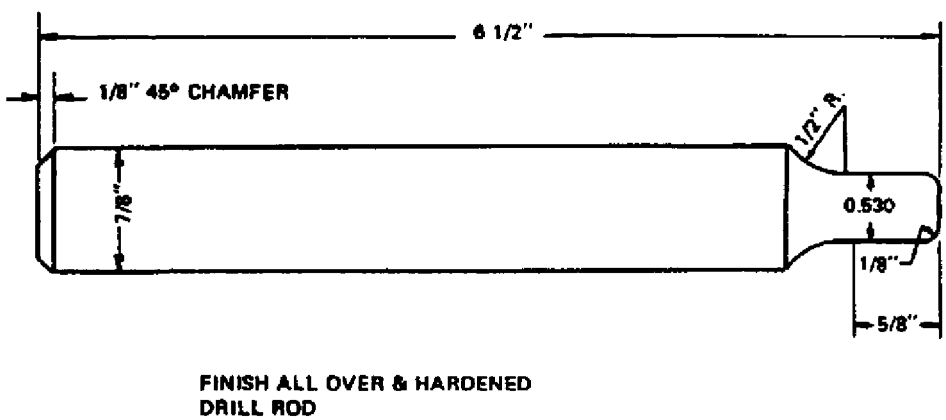



Figure 254-2-20. Tube Flaring Tool

**NOTE**

When rerolling tubes, limit each expansion to a 0.001- to 0.002–inch increase in the inside diameter.

254-2.6.24.3 Tube Flaring. Following the expanding operation, the inlet ends of copper-nickel tubes should be belled or flared to an outside diameter of not more than 3/4 inch for 5/8-inch outside-diameter tubes and 7/8 inch for 3/4-inch outside-diameter tubes. (Do not flare titanium tubes.) A flaring tool suitable for 5/8-inch outside-diameter tubes having a wall thickness of 0.049 inch is shown in Figure 254-2-20. Before expanding the tube, prepare the tube hole by reaming a 1/2-inch flare into the outer end. In general, the radius of the flaring tool should be equal to the radius of the flare reamed into the tube sheet holes. Do not drive the flaring tools into the tube end so hard that the wall of the tube is thinned or cut. After flaring, mill or grind the projecting flared ends of the tubes flush with the tube sheet surface to provide a smooth entrance for the circulating water flowing into the tubes. Flaring the outlet ends of expanded tubes is unnecessary. These ends may project up to 3/16 inch from the face of the tube sheet or may be milled flush with the tube sheet surface.

254-2.6.25 OUTLET TUBE END PACKING. Pack the outlet ends of packed condenser tubes with flexible packing specified by MIL-P-2863, grade A, Packing, Preformed, Condenser-Tube (Symbol 1435). This packing is available at most naval shipyards under the following National Stock Numbers (NSN):

a. Lead Packing, NSN 5330-00-290-5797

b. Fiber Packing, NSN 5365-00-291-5001.

254-2.6.25.1 Before calking the packing into the glands, remove the old packing and thoroughly clean the threads or serrations of the glands with a thread comb. Remove all traces of the old packing to permit proper installation of the new packing. Packing removal tools suitable for use with a 5/8-inch outside-diameter tube and a stuffing box gland depth of 3/4 inch are shown in Figure 254-2-11 and Figure 254-2-12. A thread-cleaning tool for the same size tube and stuffing box is shown in Figure 254-2-21.

254-2.6.25.2 Before packing the outlet ends, fix the inlet ends of the condenser tubes in the tube sheet by expanding.

254-2.6.25.3 For 3/4-inch deep stuffing box glands, the proper packing consists of two fiber rings and two metallic rings. To facilitate packing installation, insert a loading pin into the outlet ends of the tubes. A loading pin satisfactory for packing a 5/8-inch outside-diameter condenser tube with a wall thickness of 0.049 inch is shown in Figure 254-2-22. With the loading pin inserted into the tube end, place a fiber packing ring on the pin and calk it to the bottom of the stuffing box. Use a calking tool similar to that shown in Figure 254-2-23 for 5/8-inch outside-diameter tubes. Strike one or two light blows with a 3/4-pound hammer. Next, place a metallic packing ring on the loading pin and calk it into the packing box. Strike three or four light blows with a 3/4-pound hammer, as necessary, to force the metallic ring into the threads of the gland and to fill all voids. Repeat these operations, inserting another fiber expansion ring and another metallic ring in the same manner, calking each ring separately. If the depth of the stuffing box is greater than 3/4 inch, install an additional metallic packing ring and calk it firmly into place to fill the stuffing box completely with packing. If the stuffing box is 5/8 inch deep, only three rings of standard packing can be used. In this case, calk one metallic ring in place at the bottom of the stuffing box. Follow with a fiber ring and a second metallic ring. Do not expand, bell, or flare the outlet ends of packed condenser tubes.

254-2.6.25.4 When all the tubes have been packed, test the condenser by filling the shell with warm water. Should any of the packed ends leak, recalk the joint with light hammer blows to the calking tool. Using warm water for testing prevents condensation on tubes and tube sheets which might provide a false leak indication. Any expanded tube joints that leak during this test should be tightly rerolled.

254-2.6.25.5 It is extremely important to avoid excessive calking of the packing. Do not use a hammer larger than 3/4 pound or strike with heavy blows. Excessive force during packing may neck the tube end so that the tube is held too tightly in the packing box gland for proper movement through the gland during expansion. If a necked tube moves through the packing, the joint will leak. The loading pin shown in Figure 254-2-22 has a pilot at its inner end that closely fits the inside bore of the tube. A tube that is badly necked during packing will grip the loading pin pilot, making pin removal difficult. Any such difficulty during packing shows that the packing has been greatly overcalked. Replace such tubes immediately. Do not use air hammers for calking condenser tube joints with flexible metallic packing since this may cause excessive calking.

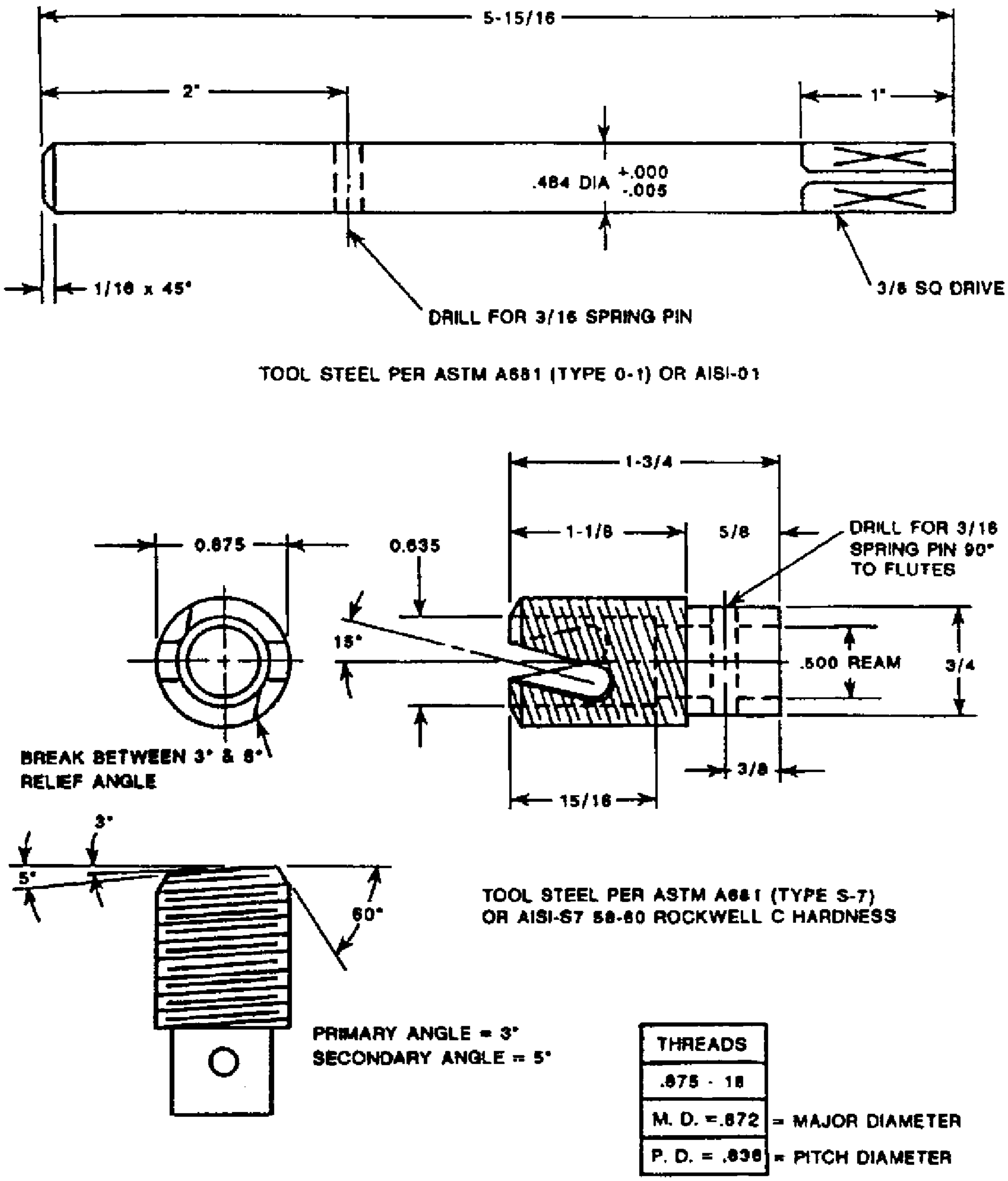



Figure 254-2-21. Thread-Cleaning Tool

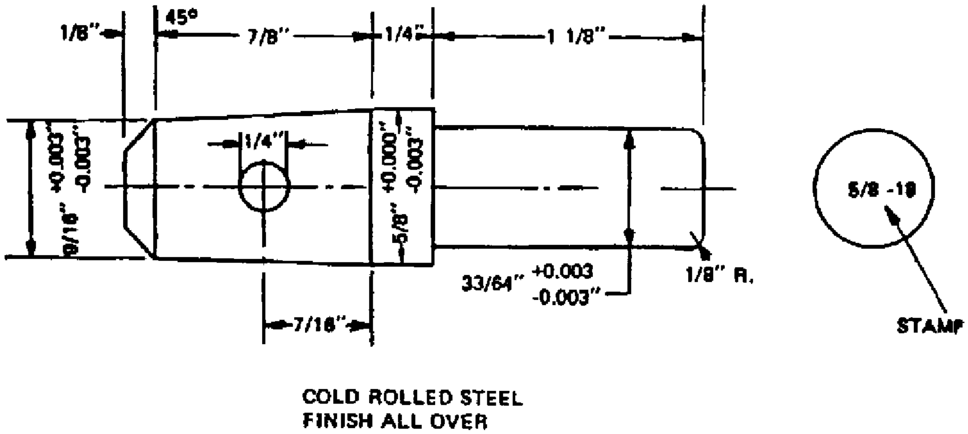



Figure 254-2-22. Packing Loading Pin

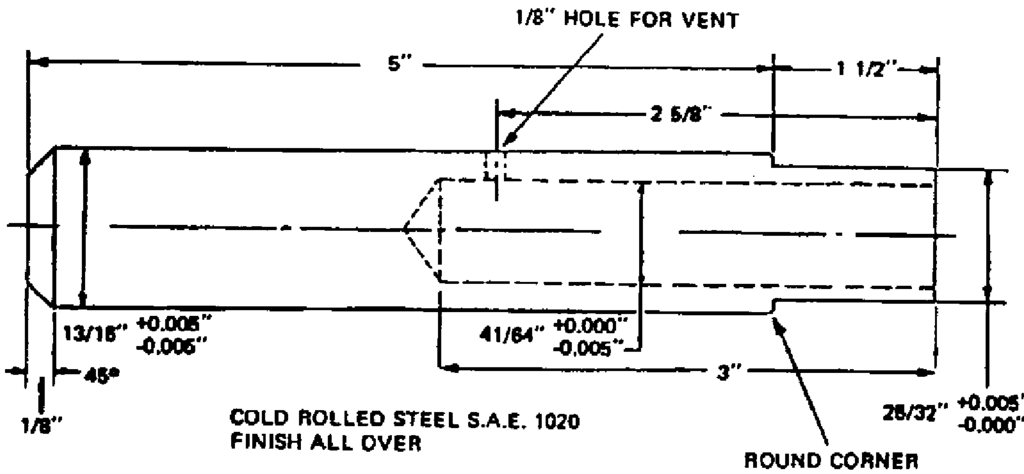



Figure 254-2-23. Calking Tool

254-2.6.26 PLUGGING ROLLED TUBE ENDS (SURFACE SHIP SINGLE-TUBE-SHEET CONDENSERS). Plug each end of damaged tubes in single-tube-sheet condensers with phenolic tube plugs conforming to MIL-P-15742, Plugs, Plastic (Heat Exchanger-Tube), (Figure 254-2-24). (For plugging packed tube ends, see paragraph 254-2.6.27). Previously, tapered plugs were longer than those shown in Figure 254-2-24 and were more susceptible to loosening or breaking. Trim any plugs not conforming to Figure 254-2-24. Drive plugs firmly into the tube ends using light hammer blows. If tube sheet holes must be plugged after the tube has been removed, make up thimbles of 70-30 copper-nickel alloy and expand them into the tube sheet holes. Short sections of tube with metal plugs seal-welded into one end can also be expanded into the tube sheet holes.

254-2.6.27 PLUGGING PACKED TUBE ENDS. A method for plugging packed tube ends is shown in the two sheets of Figure 254-2-25. Sheet 1 shows a cutaway view of the tube end and sheet 2 shows an end view with the tube plug dimensions and a list of material quantities needed for plugging one tube. Plug material must conform to MIL-C-15726, Copper-Nickel Alloy, Sheet, Plate, Strip, Bar, Rod and Wire. Use plug 1A if the tube is in place and plug 1B if the tube has been removed. Remove all packing, and clean the tube sheet threads using the tools shown in Figure 254-2-11, Figure 254-2-12, and Figure 254-2-21. Install one ring of fiber packing (MIL-P-2863, grade A), as discussed in paragraph 254-2.6.25.3. Coat the threads of the blind plug with Permatex

No. 2, or equivalent, and screw it into the tube sheet. Advance the blind plug one-eighth turn after it makes firm contact with the fiber ring. Replace plugged tubes at the first shipyard availability when the waterboxes are removed for other work. Do not plug tubes that are leaking at the tube sheet joints but are otherwise in good condition. The proper repair in such cases is to reroll or repack the tube joints, as appropriate.

254-2.6.28 PLUGGING ROLLED TUBE ENDS (DOUBLE-TUBE-SHEET CONDENSERS). Permanently plug defective tubes in double-tube-sheet condensers as soon as possible. If sufficient time is unavailable for permanent plugging, however, defective tubes may be temporarily plugged with tapered phenolic plugs (paragraph 254-2.6.26). Tapered phenolic plugs are acceptable only for forces afloat. Likewise, only shipyard or tender personnel should permanently plug tubes as it is difficult and time consuming. Permanent plugging involves cutting the tube at the outer face of the inner tube sheet, removing the tube stub, and rolling a stepped thimble into the original tube in the inner tube sheet and outer tube sheet hole. Permanent tube-plugging tool sets are available from the stock system (and may be carried on board tenders) for every saturated-steam plant double-tube-sheet condenser and are listed on the appropriate Allowance Parts List. These tool sets contain 100 permanent plugs and all the necessary tools and instructions for installation.

**NOTE**

Do not use permanent tube plugs when leakage is due to a loose rolled tube joint that can be rerolled. Ensure that the tube is defective before installing permanent tube plugs.

254-2.6.29 TESTING PLUGGED, REPACKED, OR REPLACED TUBES. After plugging, repacking, or replacing condenser tubes, verify the seawater side integrity for single- or double-tube sheet condensers according to the following procedures.

254-2.6.29.1 Surface Ship Single-Tube-Sheet Condensers. Test surface ship single-tube-sheet condensers as described in the following paragraph. When rerolling tubes, limit each expansion to a 0.001- to 0.002-inch increase in the inside diameter.

**NOTE**

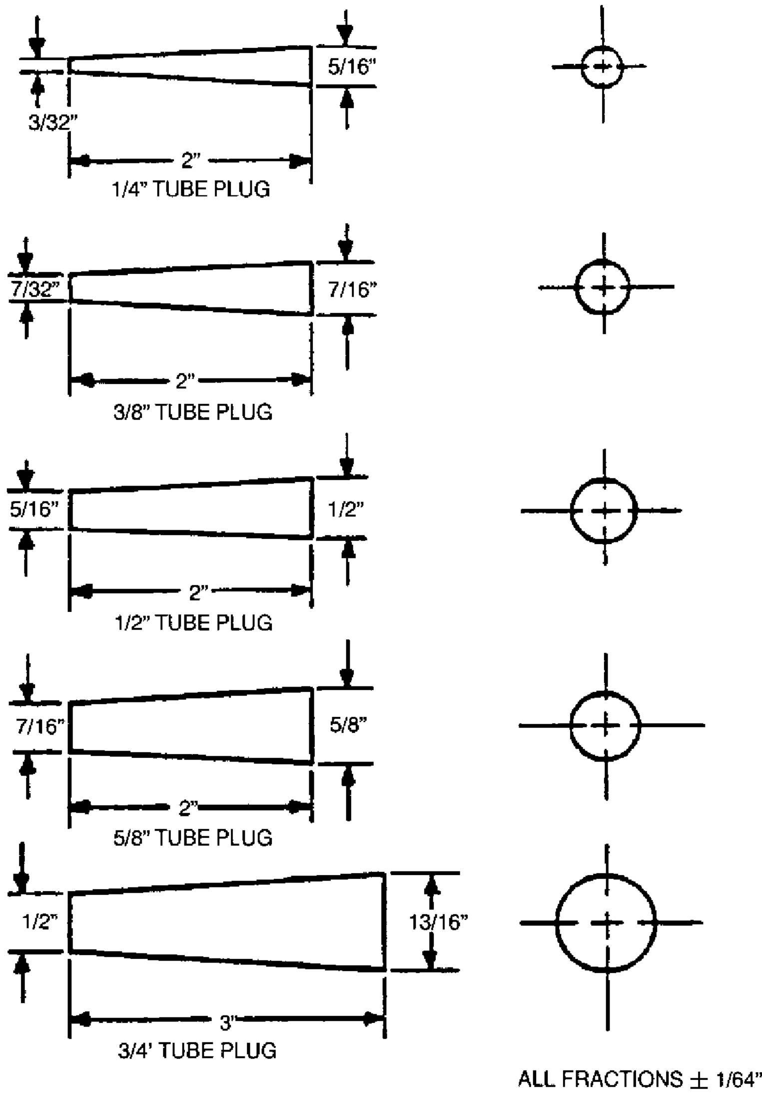
Before removing waterboxes, consult the manufacturer’s technical manual for additional bolting or test rings to replace the support normally provided by the waterboxes.

254-2.6.29.1.1 If the waterboxes were removed during repairs, hydrostatically test the seawater side according to the manufacturer’s technical manual. If the appropriate technical data are unavailable, use the following pressures:

a. 54 psig on CV 67 and CVN 68 class ships, 41 psig on CGN 36/38 class ships, and 30 psig on all other ships for strength tests (if structural welding or structural shell repairs have been made).

254-2.6.29.1.2 If waterboxes were not removed and no other repairs were made to seawater pressure boundaries, check for leaks during the initial filling and startup.

254-2.6.29.2 Double-Tube-Sheet Condensers. On double-tube-sheet condensers, perform a void space test as described in paragraph 254-2.6.12.7, except pressurize the void space to 110 percent of submergence pressure or seawater system design pressure, as applicable to the ship installation. When rerolling tubes or permanent tube plugs, limit each expansion to a 0.001- to 0.002-inch increase in the inside diameter. Test the seawater side as described in paragraphs 254-2.6.29.1.1 or 254-2.6.29.1.2, as applicable.




| NOMINAL PLUG SIZE | MILITARY PART NO. | NATIONAL STOCK NO. |
|---|---|---|
| 1/4" | M15742–2 | 4730–00–337–6753 |
| 3/8" | M15742–3 | 4730–00–289–0593 |
| 1/2" | M15742–4 | 4730–00–821–0795 |
| 5/8" | M15742–5 | 4730–01–029–2857 |
| 3/4" | M15742–6 | 4730–00–289–0595 |

Figure 254-2-24. Tapered Phenolic Tube Plugs

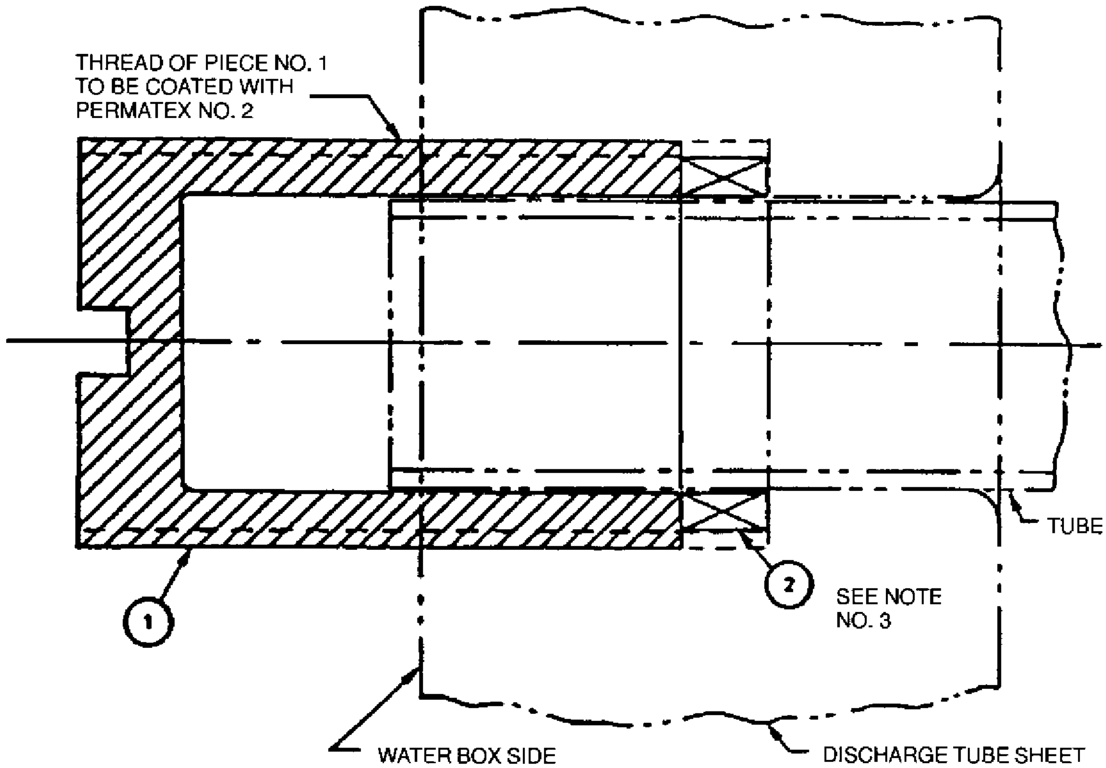


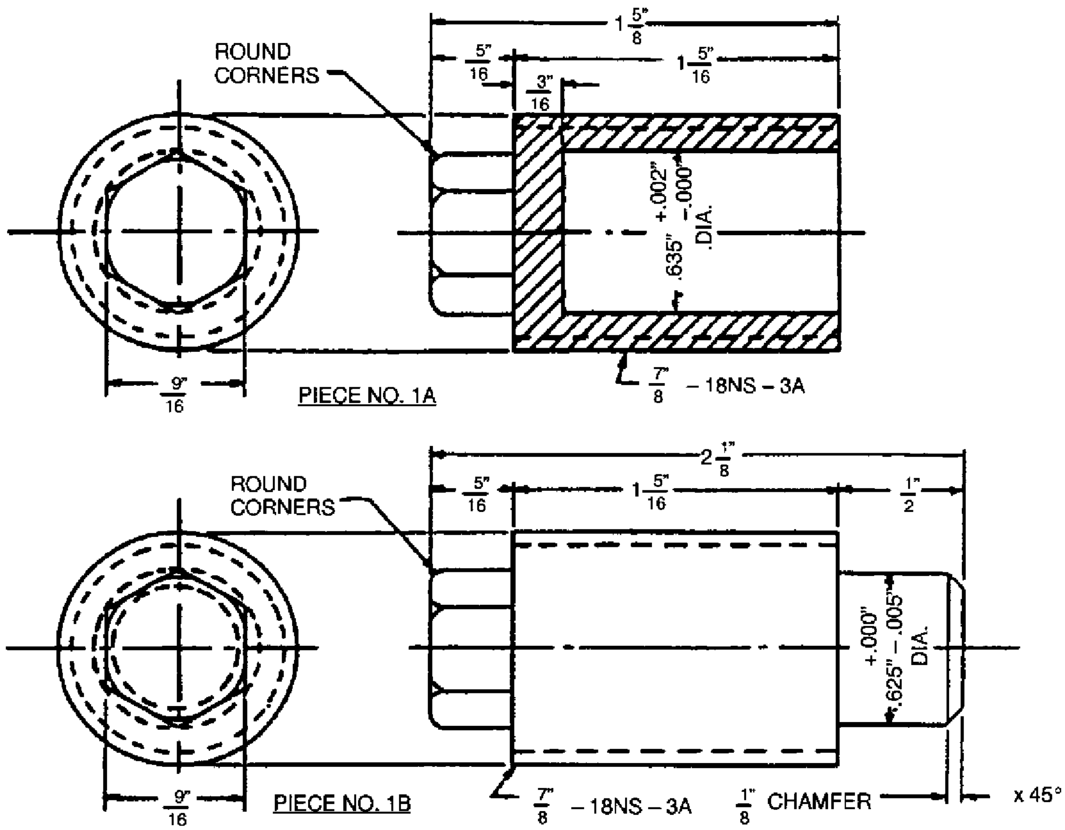

Figure 254-2-25. Plugging Packed Tube Ends (Sheet 1 of 2)

a. Notes:

1. Toroughly clean threads in existing tube sheet before installing Pc No. 1

2. Advance PC No. 1 toward Pc No. 2 one-eighth turn after firm contact at assy.

3. Packing be be calked in accordance with paragraph 254–2.6.25.3




| LIST OF MATERIAL–QUANTITY FOR ONE TUBE PLUGGING | | | | | | |
|---|---|---|---|---|---|---|
| Pc. No. | Description | Qty | Mate-rial | Specifi-cation | Stock No. | Remarks |
| 1A | Plug. Screwed | 1 | 70-30 Cu-Ni | MIL–C–15726 | | See Detail |
| 1B | Plug. Screwed | 1 | 70-30 Cu-Ni | MIL–C–15726 | | See Detail |
| 2 | Packing | 1 | Fiber | MIL–P–2663B | Grade A | 25/32" OD x 5/8" ID x 3/16" LG |

Figure 254-2-25. Plugging Packed Tube Ends (Sheet 2 of 2)

**NOTE**

If the waterboxes are removed, consult the component technical manual before pressurizing the void space to determine if additional bolting or a tube sheet brace is required to replace the support normally provided by the waterboxes.

254-2.6.30 TEMPORARY IMPINGEMENT BAFFLE. If several tube leaks occur near a steam or water inlet to the condenser shell and steamside erosion is suspected, inspect all connections in the area for pipe or baffle failure. To prevent further tube erosion, an effective temporary baffle can be made by installing steel rods of slightly smaller diameter than the tube bore into each failed tube. Insert phenolic tube plugs into these and all adjacent tubes in the affected area of the condenser. To prevent end-to-end movement of the steel rods (which might tend to loosen the plugs) take the following steps:

1. Cut the steel rods as long as possible without interfering with the proper installation of phenolic tube plugs.

2. Cut two grooves in each end of the rod about an inch apart, starting about 2 inches from each end. Make each groove the proper depth and width to contain a standard condenser tube fiber packing ring.

3. Cut a segment from each fiber packing ring (one for each groove) so that when the ring ends are brought together, the ring shall fill the groove and fit snugly inside the tube.

4. Insert the rods (and the packing rings) into the tubes to be plugged. Center the rods properly, spray the packing with freshwater, and install the tube plugs.

254-2.6.31 SHELL FLANGE-TO-TUBE SHEET GASKET REPAIR. Leaks are rarely caused by failure of the gasket between the shell flange and the tube sheet in fixed-bundle heat exchangers if the shoulder bolts (usually provided in these exchangers) are properly used. Replacing gaskets requires costly retubing of the complete exchanger. Should a leak occur in such a joint, repair the joint as follows (and as shown in Figure 254-2-26) to avoid the need for retubing:

**NOTE**

For saturated steam plant condensers, obtain approval of NAVSEA 034Z43 before using this repair procedure.

1. Cut a circumferential groove around each of the bolts that secure the joint between the shell flange and tube sheet. This groove should be 1/8-inch wide by 1/16-inch deep, and must line up with the joint to be sealed.

2. Drill a 1/8-inch hole from the bottom of the groove toward the center of the bolt. The hole must be at least halfway through the bolts.

3. Drill a 1/8-inch hole axially through the head and body of the bolt to intersect the hole drilled from the groove.

4. Tap the hole in the bolt head for a pressure-type grease fitting.

5. Loosen the joint slightly.

6. Inject a nondrying, gasket-forming compound such as Permatex number 3, Dow Corning Silastic RTV 732, or equivalent, into the holes drilled in the bolts

7. Tighten the joint.

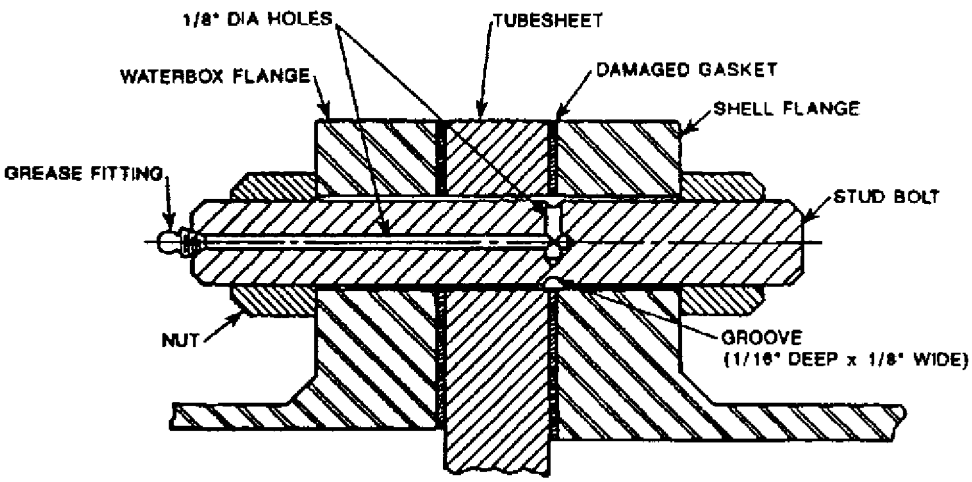



Figure 254-2-26. Shell Flange-to-Tube Sheet Gasket Repair

254-2.6.32 WATERBOX AND TUBE SHEET EPOXY REPAIR. Epoxy coatings can be used to repair erosion/corrosion damage to tube sheets and waterboxes of steam condensers on superheated steam plant surface ships. Epoxy coatings can also be used to replace the rubber linings of steel waterboxes. When authorized, the application of epoxy to tube sheets or waterboxes shall be in accordance with the following general guidance.

**NOTE**

Epoxy repairs to steam condensers and propulsion plant heat exchangers on saturated steam plant ships is not authorized for structural reasons.

**NOTE**

Seawater-wetted surfaces of Alloy 625 or Alloy C-276 shall not be repaired with epoxy unless specifically approved by NAVSEA.

**CAUTION**

**Many condensers have waterboxes internally coated with a lead-tin solder. The removal or repair of existing solder coating is a potentially toxic procedure. Solder coating repair is not required. Refer to 254-2.6.21.1.**

254-2.6.32.1 Inspection. Inspect the areas to be repaired. For steam condensers on superheated steam plant ships, if a defect causes the waterbox or tube sheet thickness to be less than 2/3 of the original thickness, the area(s) shall be repair welded or replaced to restore to original thickness.

254-2.6.32.2 Surface Preparation. The surface to be coated must be carefully prepared to provide a good anchor for the epoxy. Corrosion, salt deposits, dust, moisture, oil, and grease must be completely removed prior to epoxy application. Surface preparation applies to the area to be coated, plus a minimum of 1/2 inch beyond this area on all sides. The epoxy coating shall not extend onto unprepared surfaces.

a. Water Removal. When repairing tube sheets, or waterbox surfaces adjacent to the tube sheet, any standing water in the tubes should be blown out using an air line. The process should be continued until the tubes are dry. When repairing waterbox surfaces, all standing water should be removed and the surfaces blown dry using an air line.

b. System Protection. Use appropriate piping plugging devices to ensure that fluids and particles used to prepare surfaces do not contaminate attached piping. When repairing tube sheets, or when waterbox repairs could potentially damage or contaminate condenser tubes, the tubes require temporary plugging. Corks of maximum diameter slightly greater than the internal diameter of the tubes should be obtained. One cork should then be pushed into each tube of concern, and when all tubes are plugged, a flat piece of wood, metal bar, etc., shall be used to level all the corks with the tube ends.

c. Grease and Oil Removal. Thoroughly clean surfaces which are to come in contact with epoxy using a non-ionic, biodegradable, water-soluble detergent or a degreaser/cleaner recommended by the epoxy manufacturer. Afterwards, surfaces shall be solvent cleaned prior to any preliminary surface conditioning.

d. Preliminary Surface Conditioning. Prior to any surface conditioning, the surrounding areas that are not to be reconditioned shall be masked with a material that provides adequate protection. The surface to be prepared shall be conditioned to produce a 0.003″ to 0.005″ anchor tooth profile. Surface conditioning shall be accomplished by abrasive blasting, needle gun, or grinding. The use of a wire brush or sanding disk is to be avoided as the resultant ″polishing″ may leave the surface too smooth for proper adhesion of the epoxy.

e. Salt Removal. Wait at least 24 hours following preliminary surface conditioning to allow ingrained salts to crystallize on the surface of the metal. Crystallized salt will be removed during oxide removal.

f. Oxide Removal. A final abrasive cleaning shall be done to remove any surface oxides or contamination left from previous cleaning procedures and to obtain a final surface profile that promotes adhesion of the epoxy coating. The same methods used for preliminary surface conditioning shall be used for this cleaning.

g. Final Cleaning. Immediately following oxide removal, but prior to coating, the surface shall be cleaned with the same solvents used for oil and grease removal. The surface shall be cleaned until it is free of oil, grease, dirt, mill scale, rust, corrosion products, oxides, and other foreign matter.

**NOTE**

Avoid contacting surfaces to be coated with the bare hand or other sources of contamination.

**CAUTION**

**The first coating of epoxy should be applied immediately following oxide removal and final cleaning to avoid oxide formation. If the epoxy is not applied within 4 hours, the oxide removal and final cleaning steps must be repeated.**

**NOTE**

NAVSEA S9520-AA-MMA-01/VOL I (Repair of Submarine Seawater Ball Valves (Non-Nuclear)) and NAVSEA Technical Publication 03Y3-100 (Pump Repairs Using Polymeric Compounds) provide acceptable alternate procedures to accomplish the required surface preparation.

254-2.6.32.3 Application. Care must be exercised when selecting an epoxy to match the environment, operating fluid, and waterbox material of the condenser. NAVSEA Technical Publication 03Y3-100 contains a listing of various epoxies and associated physical properties. Epoxy Material Selection and Handling shall be in accordance with NAVSEA Technical Publication 03Y3-100. The mixing and application of the epoxy shall be in accordance with the manufacturer's instructions and NAVSEA Technical Publication 03Y3-100.

254-2.6.32.4 Finish Machining. Careful application of the epoxy can often reduce or eliminate any required machining. Careful buildup and fairing of the material or the application of multiple layers slowly approaching the desired thickness is often much less labor intensive than machining or grinding off excess material. However, if machining is required, it should be accomplished in accordance with the requirements of NAVSEA Technical Publication 03Y3-100 and the manufacturer's instructions. Wet or dry grinding with aluminum oxide or silicon carbide grinding wheels can be used to remove excess material. Care must be taken during any machining operation to avoid damaging the coating.

254-2.6.32.5 Final Inspection. The coating should be free from cracks, areas of separation, blisters, rough surfaces, areas of porosity or areas of discoloration. There should not be an excessive build-up of epoxy coating on the surface in question. Any discrepancies of the aforementioned types are cause for coating repair.

254-2.6.32.6 Coating Repair. Epoxy coating repair and the application of an epoxy coating over an existing one is to be accomplished in accordance with the requirements of NAVSEA Technical Publication 03Y3-100.

## SECTION 3.

## SHELL-AND-TUBE HEAT EXCHANGERS

### 254-3.1 GENERAL

254-3.1.1 RELATED INFORMATION. Since condensers are a type of shell-and-tube heat exchanger, much of the information in Section 2 is applicable to other types of shell-and-tube units. Rather than repeat this information in this section, it is referred to as necessary. This is especially true of the maintenance procedures, most of which are identical for all shell-and-tube heat exchangers.

254-3.1.1.1 The basic principles of heat transfer have already been discussed in Section 1. Most hell-and-tube heat exchangers operate at or above atmospheric pressure, so the discussions in Section 2 on regulating and maintaining vacuum do not apply. In fact, most heat exchangers require no attention other than monitoring temperatures and pressures and regulating the fluid flows to maintain the proper system parameters.

254-3.1.2 SCOPE. Unlike condensers (all of which are of a few basic designs), the Navy uses a wide variety of shell-and-tube heat exchanger designs, making detailed descriptions of each design impossible. Almost all of this equipment, however, is built by combining a few basic components in different ways. This section will describe these components rather than particular designs made from them.

### 254-3.2 ENGINEERING PRINCIPLES

254-3.2.1 FLOW ARRANGEMENT. Three basic flow relations can exist between the fluid inside the tubes (called tubeside) and that outside the tubes (shellside): parallel flow, counterflow, and crossflow.

254-3.2.1.1 Effect on Heat Transfer. The flow arrangement significantly affects a heat exchanger's heat transfer capability. Equation 1.1 (paragraph 254-1.2.4.1) showed that the heat transfer rate depends on the temperature difference (or delta-T) between the two fluids. Since both fluids are changing temperature as they move through the heat exchanger, delta-T also differs from point to point. The way delta-T changes primarily determines the heat transfer effectiveness of the various flow arrangements.

254-3.2.1.2 Parallel Flow. In parallel flow, the hot and cold fluids enter at the same end of the unit and flow parallel to each other to the opposite end (Figure 254-3-1). This produces the maximum possible delta-T and high heat transfer rates at the inlet end. Flowing through the unit, however, the hot fluid cools down and the cold fluid heats up. In other words, delta-T decreases continually along the flow path, creating an imbalance in heat transfer. Very little heat is transferred at the outlet end of the heat exchanger.

254-3.2.1.3 Counterflow. In counterflow, the fluids enter at opposite ends of the unit (Figure 254-3-2), maintaining a more even delta-T through the length of the exchanger. Consider an example with the hot fluid in the tubes and the cold fluid in the shell. The hot fluid is at its maximum temperature as it enters and cools down as it flows through the tubes. The cold fluid heats up as it flows through the shell, but it is flowing in the opposite direction. This means that it is coolest where the hot fluid is coolest (at the tube outlet) and hottest where the hot fluid is hottest (at the tube inlet). Heat transfer is thus more constant throughout the heat exchanger, giving better overall performance for counterflow than for parallel-flow units.

254-3.2.1.4 Crossflow. In crossflow, the two fluids flow at right angles to each other (Figure 254-3-3), (that is, the shellside fluid flows across rather than along the tubes). Crossflow heat exchangers give performance between that of parallel-flow and counterflow units.

254-3.2.1.5 Pass Arrangement. The flow patterns previously described are simple one-pass arrangements. Each fluid enters at one end, makes one pass through the exchanger, and exits at the opposite end. (For crossflow, the shellside fluid enters at the middle of one side, flows across the bundle, and exits from the opposite side.) Few actual designs are so simple. Most exchangers have baffles that route the shellside flow back and forth across the bundle, giving a crossflow arrangement regardless of where the fluids enter and exit. Many exchangers use partitions in the tubeside inlet and outlet areas to create multipass flow patterns (where the tubeside fluid flows back and forth through the exchanger before exiting). While these flow patterns may not be as effective (in theory) as pure counterflow, they offer certain advantages in practical applications, most of them from the increased fluid velocity created by using multiple passes or baffles.

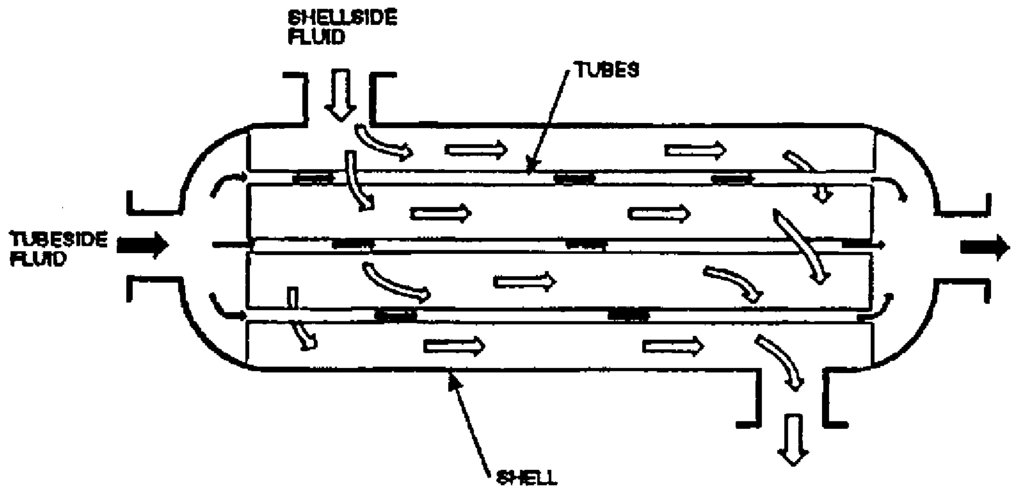



Figure 254-3-1. Parallel Flow Schematic

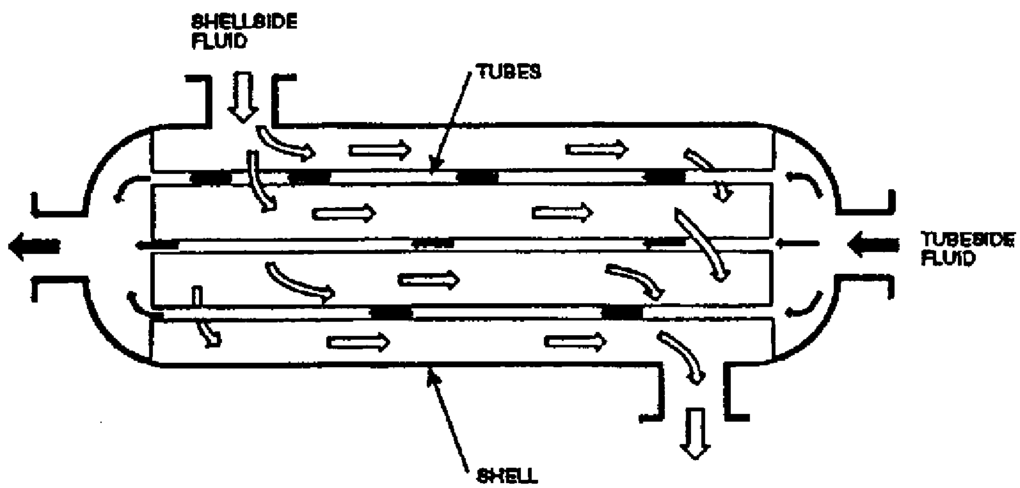



Figure 254-3-2. Counterflow Schematic

254-3.2.2 VELOCITY EFFECTS. Fluid velocity strongly affects heat transfer. Since convection depends on the movement of the fluid to carry heat to (or away from) a surface, the faster a fluid moves the more heat it can transfer. Increases in velocity also tend to make fluid flow more turbulent. This is important since in laminar (nonturbulent) flow a boundary layer forms near the tube surfaces. This thin but nearly stationary layer of fluid acts as an insulator, blocking heat transfer. In turbulent flow, this layer is continuously broken up and carried away. One of the benefits of crossflow is that flow across tubes is much more turbulent than flow along tubes.

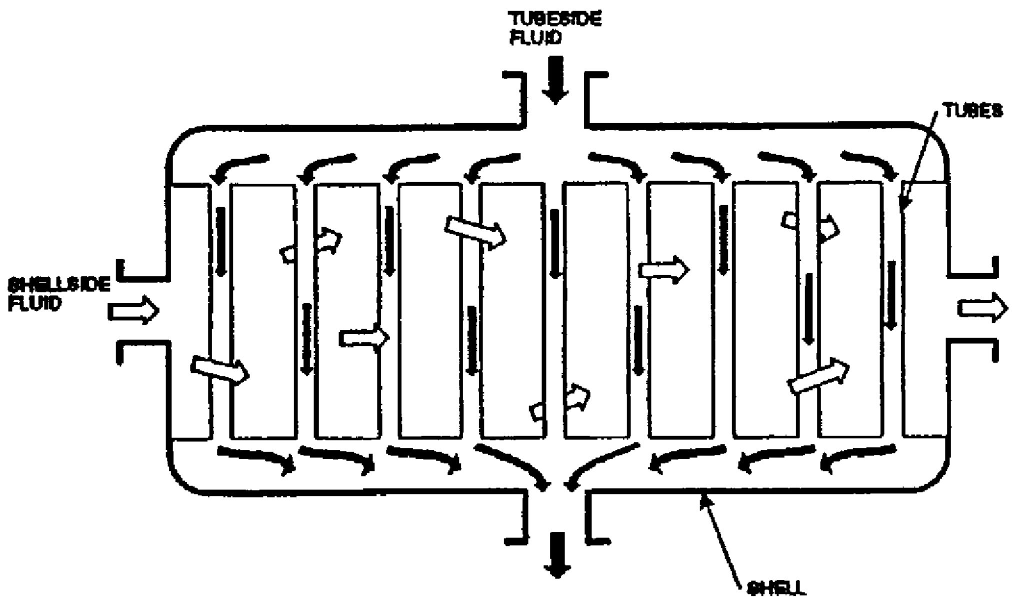



Figure 254-3-3. Crossflow Schematic

## 254-3.3 EQUIPMENT DESCRIPTION

254-3.3.1 GENERAL. Even though there is a wide variety of shell-and-tube heat exchanger designs, all make use of the same basic components: a shell, head(s), and a tube bundle. Detailed requirements for U.S. Navy heat exchangers are given in MIL-C-15730, Coolers, Fluid, Naval Shipboard: Lubricating Oil, Hydraulic Oil, and Freshwater.

254-3.3.2 SHELL TYPES. Most Navy shell-and-tube heat exchangers have cylindrical shells, sized to fit closely around the tube bundle so that little flow bypasses the bundle. The shell wall thickness is based on structural and pressure requirements. Flanges are provided at one or both ends for attaching the head(s). Inlet and outlet nozzles for the shellside fluid are also usually located near the ends of the shell. In most designs these nozzles are at opposite ends, and the shellside fluid makes one pass through the shell. In some designs the shell has longitudinal baffles to direct the shellside flow through two or more passes. In such cases the nozzles may be at the same end or even in the middle.

254-3.3.2.1 For heat exchangers in which removing the tube bundle is unnecessary (fixed-bundle), the tube sheets may be permanently attached to the shell. Tube sheets are thick plates into which the tubes are rolled, packed, or otherwise attached. The tube sheets support and space the tubes, and seal the ends of the shell to contain the shellside fluid. In many fixed-bundle units, the tube sheets and shell flanges are machined from the same plate and then welded to the shell. Since different metals expand differently when heated, fixed-bundle units often have some sort of shell expansion joint. This allows the shell and tubes to expand at their own rate during heatup. An expansion joint may not be required if the two metals have similar expansion properties, if the temperature differences are small, or if the shell and tubes are sized to withstand the stresses produced by unequal expansion.

254-3.3.3 HEAD TYPES. All of the many front and rear head designs serve the same basic purposes, to contain and direct the tubeside flow. The heads are either cast or fabricated and are bolted to the shell flanges. Front heads contain an inlet nozzle (and an outlet nozzle on units with an even number of tube passes). There may also be division plates to direct the tube flow from one tube pass to another. Rear heads may or may not have an outlet nozzle, again depending on the desired tubeside flow pattern. Rear heads may also have division plates. Rear heads with no nozzle are sometimes called return heads.

254-3.3.4 TUBE BUNDLES. The tube bundle is the heart of the heat exchanger; the place where heat transfer occurs. Tube bundles consist of tube sheets (either removable or nonremovable) and tubes, with support and baffle plates as needed.

254-3.3.4.1 U-Tube Bundles. The simplest type of removable tube bundle is the U-tube type (Figure 254-3-4). In these bundles, the tube sheet is symmetrical about a centerline. All the tubes are bent into U shapes and inserted into the tube sheet, starting with the tightest bends in the middle of the tube sheet and working outward to the large radius bends. A division plate in the front head directs all the flow into one end of the tubes (1/2 of the tube sheet). Since the tubeside flow is returned to the front head by the U-tubes, no rear head is required. The shell is simply closed with a plate. U-tube heat exchangers allow for unequal expansion of tubes and shell since the tubes are unrestrained on the U end. They are difficult to clean mechanically, however, and prevent individual tube replacement except for the outermost tubes.

254-3.3.4.2 Straight-Tube Bundles. In straight-tube bundles, the tubes are held in tube sheets at each end of the heat exchanger. For nonremovable bundles, these tube sheets are permanently attached to the shell (Figure 254-3-6). These exchangers are simple and inexpensive, but can be difficult to clean and repair since all such work must be done with the tube bundle in place. All heat exchangers built to MIL-C-15730 are required to have removable tube bundles.

254-3.3.4.3 Floating-Head Tube Sheet Designs. Heat exchangers with removable bundles are easier to maintain and allow relative motion between the shell and tube sheet to account for unequal expansion. They do this by using a fixed tube sheet (bolted to the shell) and a floating tube sheet (free to move). Floating tube sheets are also called floating heads. The only type of floating-head design commonly used by the U.S. Navy is the outside-packed lantern ring. This design (Figure 254-3-7) uses a lantern ring, held between the shell flange and the rear head, to seal a floating tube sheet. The lantern ring is packed on both sides and has weep holes for leak detection.

254-3.3.4.4 Double Tube Sheets. When it is critical that the shellside and tubeside fluids not be mixed, double tube sheets are often used. In this design (Figure 254-3-7), tubes are fixed into two tube sheets at each end. Any leaks (tubeside or shellside) at tube-to-tube-sheet joints thus leak into the space between the tube sheets and not into the other fluid. (Fluid mixing due to tube leaks, however, can still occur.) Double tube sheets are used only on heat exchangers having fixed tube sheets, U-tubes, or outside-packed stuffing boxes.

254-3.3.4.5 Tube Supports and Baffles. All but the smallest shell-and-tube heat exchangers require some sort of support for the tube bundle. Vibration of long, unsupported tube spans, excited by turbulent shellside flow, can lead to early tube failure. Shellside heat transfer can be increased with directional baffles (Figure 254-3-8). These baffles partially block the shellside (alternating between top and bottom), sending the flow in a zigzag pattern. This has several advantages. The shellside flow area is directly related to baffle spacing, giving control of fluid velocity. The baffles also force the flow across, rather than along, the tubes, increasing turbulence, and eliminating dead areas. When baffles are used the flow between them is always crossflow. The overall flow pattern as the shellside fluid progresses from baffle to baffle, however, can be either parallel, counter, or cross, depending on the nozzle locations.

## 254-3.4 OPERATION

254-3.4.1 Most shell-and-tube heat exchangers are passive devices; that is, they have no controls and require no actual operation. Any specific operating procedures that are required (such as controlling one or both flows to maintain the proper pressures and temperatures) depend on the system served by the heat exchanger and are not discussed here. General procedures on throttling flow to a heat exchanger can be found in paragraph 254-2.4.6. Temperature restrictions on seawater-cooled heat exchangers are given in paragraph 254-2.6.19.2.4. For guidance on operating seawater-cooled heat exchangers with newly installed copper-nickel tubes, see paragraphs 254-2.6.15.1 and 254-2.6.15.2.

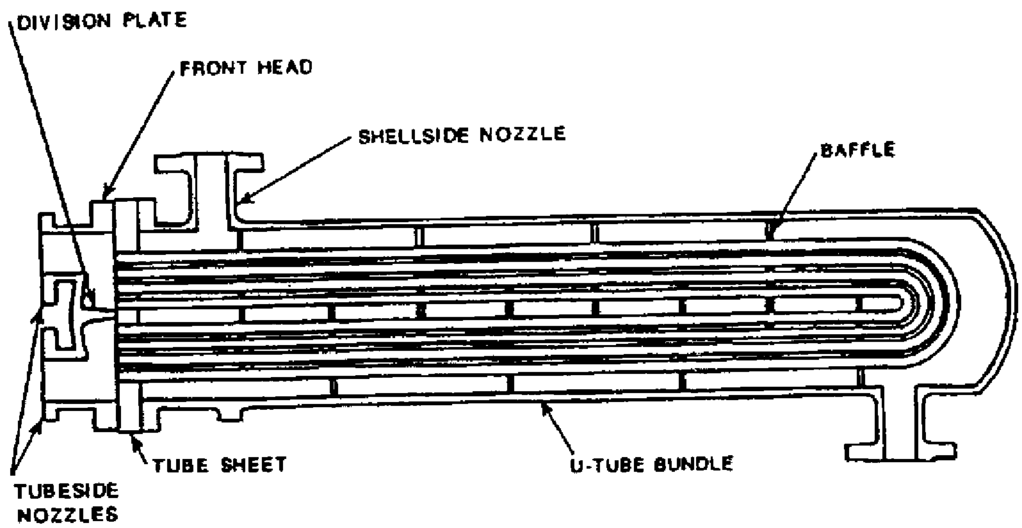



Figure 254-3-4. U-Tube Heat Exchanger

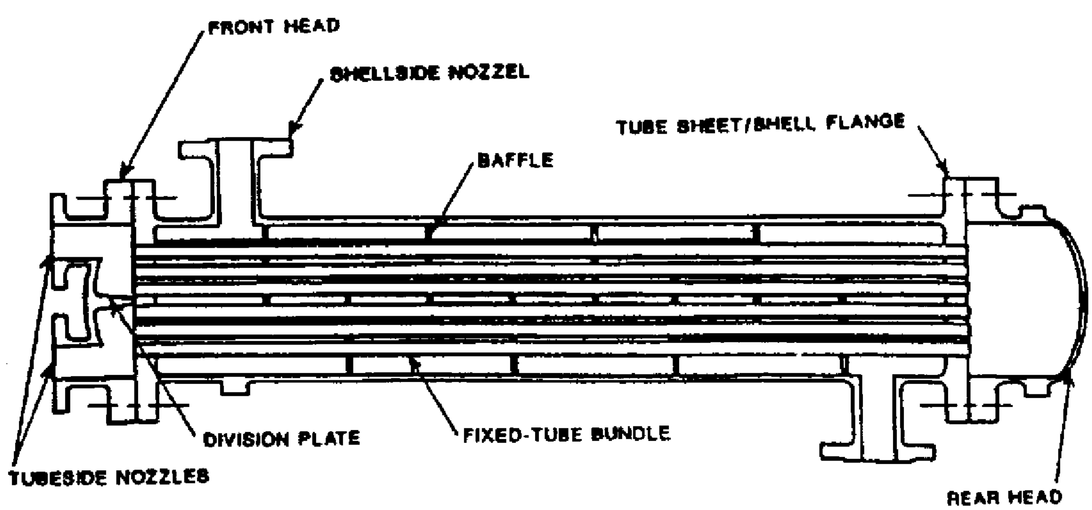



Figure 254-3-5. Fixed-Bundle Heat Exchanger

## 254-3.5 MAINTENANCE

254-3.5.1 GENERAL. Because most maintenance procedures for shell-and-tube heat exchangers are identical to those for the condensers discussed in Section 2, they are not repeated here. Instead, the appropriate Section 2 paragraphs will be referred to and expanded as necessary.

254-3.5.2 SAFETY PRECAUTIONS AND GENERAL MAINTENANCE PROCEDURES. Before opening any heat exchanger for maintenance, read paragraph 254-2.6.1 and carry out all applicable safety precautions. Also observe all CAUTIONS and WARNINGS preceding the specific maintenance procedures from Section 2. Refer to paragraph 254-2.6.2 for general maintenance procedures.

254-3.5.3 INSPECTING AND CLEANING THE TUBESIDE. As with condensers, tube fouling, scaling, and blockage will reduce heat transfer and can lead to tube damage through erosion or corrosion. General information on tubeside inspection can be found in paragraph 254-2.6.4. Methods for removing soft and hard fouling can be found in paragraphs 254-2.6.6 and 254-2.6.7, respectively. An additional method for removing soft fouling, backflushing, is described in the following paragraphs.

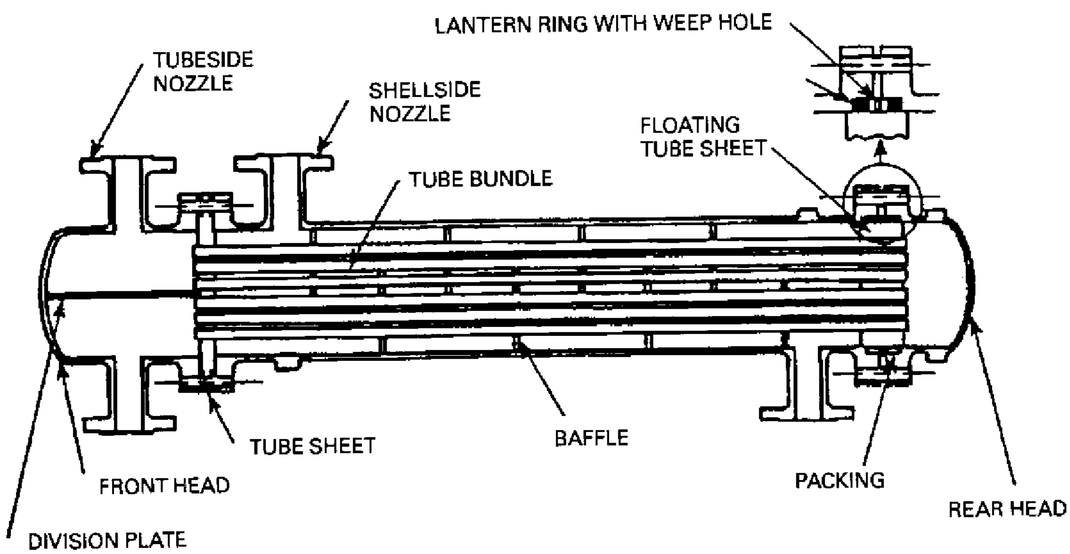



Figure 254-3-6. Fixed Bundle Heat Exchanger

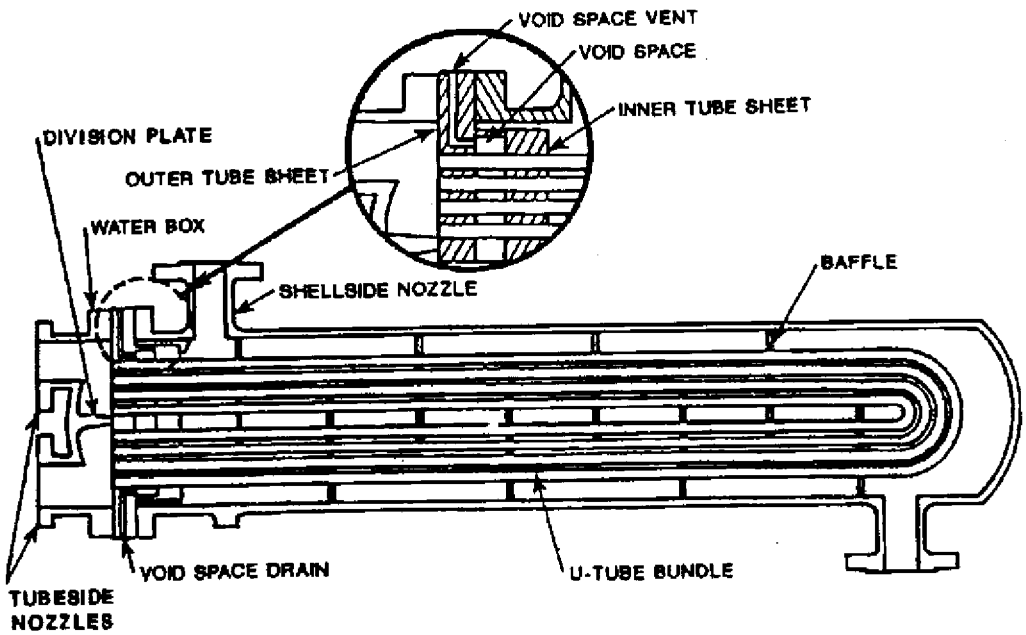



Figure 254-3-7. Outside-Packed Lantern Ring Floating Head

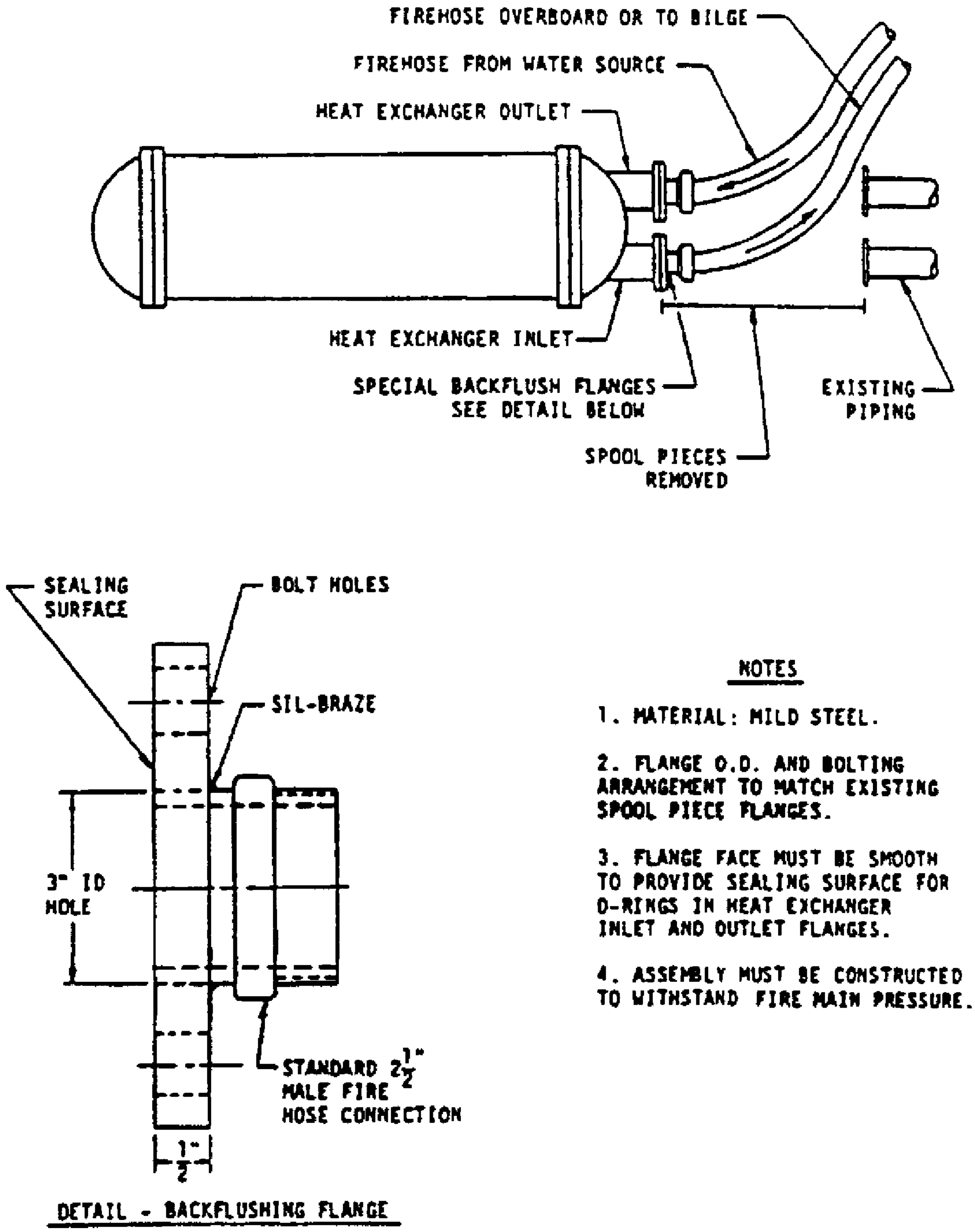



Figure 254-3-8. Backflushing Arrangement and Flange Details

254-3.5.3.1 Backflushing. Backflushing will not remove all traces of soft fouling, but it can extend the interval between mechanical cleaning of heat exchangers. (This procedure is not applicable to large units such as main and auxiliary condensers.) This could be especially beneficial to ships operating in warm or highly silted waters. The advantage of backflushing is that it requires only minor system disassembly and is therefore a simple procedure that can be quickly performed by shipboard personnel. Backflushing has several limitations, however, being most effective on single-pass, straight-tube, and two-pass U-tube units and least effective on units with more passes. Also, piping connections to the heat exchanger must allow for easy removal of spool pieces and connection to firemains (Figure 254-3-8).

254-3.5.3.1 Backflushing Procedure. The backflushing procedure is as follows:

1. Disconnect the spool pieces from the heat exchanger inlet and outlet and attach the specially constructed flanges shown in Figure 254-3-8. Use standard 2-1/2 inch firehose to connect the outlet flange to a source of firemain water. Connect another 2-1/2 inch firehose to the inlet flange. Direct this hose overboard or to the bilge, depending on the heat exchanger's location in the ship.

**WARNING**

**Firemains operate at approximately 150 psig. Construct flanges to withstand this pressure. Secure the discharge firehose to prevent whipping.**

2. If the special flanges cannot be attached directly to the heat exchanger, connect the firehoses to the piping system as close to the heat exchanger as possible. Ensure that there are no check valves or alternative flow paths in the final circuit.
3. Flush the heat exchanger with firemain water. Continue flushing until the discharge is clear and free of debris.

254-3.5.4 BLOCKED TUBES. Refer to paragraph 254-2.6.8.

254-3.5.5 INSPECTING AND CLEANING THE SHELLSIDE. Refer to paragraphs 254-2.6.9 and 254-2.6.10. Much of the information there is applicable only to condensers. Since many heat exchangers are used in less critical applications than condensers and since many operate with less damaging fluids than seawater and steam, inspection and cleaning requirements may not be as stringent.

254-3.5.6 TUBE AND TUBE JOINT LEAKS. General information on identifying and locating tube leaks, some of which is applicable only to condensers, can be found in paragraph 254-2.6.11. Specific methods for locating tube leaks in single-tube-sheet heat exchangers can be found in paragraph 254-2.6.12. Methods 1 through 3 test the entire unit at once. If these methods detect but cannot locate leaking tubes, use methods 4 and 5 to test individual tubes. A method for detecting leaks in tube-to-outer-tube-sheet joints in double-tube-sheet units can be found in paragraph 254-2.6.12.7. Although all of these methods are primarily intended for condenser use, they can also be used on heat exchangers. Paragraph 254-2.6.13 describes various types of tube leaks.

254-3.5.7 CORROSION. Paragraph 254-2.6.14 describes galvanic corrosion and its prevention (using zincs for cathodic protection). Paragraph 254-2.6.18 describes stray current corrosion.

254-3.5.8 OTHER TUBE DEGRADATION. Other forms of tube attack and damage discussed in Section 2 are tubeside erosion/corrosion (paragraph 254-2.6.15), deposit attack (paragraph 254-2.6.16), and dezincification (paragraph 254-2.6.17).

254-3.5.9 HEAT EXCHANGER HEAD MAINTENANCE. Paragraph 254-2.6.21 provides general information on maintaining heat exchanger heads.

254-3.5.10 SPECIMEN TUBE INSPECTION. Paragraph 254-2.6.22 describes the conditions under which specimen tubes should be removed for inspection and the information to be forwarded to the Naval Sea Systems Command (NAVSEA).

254-3.5.11 TUBE REPLACEMENT. Section 2 describes detailed procedures for condenser tube replacement that may also be applicable to heat exchangers. The following subjects are discussed: complete retubing (paragraph 254-2.6.23.2); tube material, length, and insertion techniques (paragraphs 254-2.6.23.3 through 254-2.6.23.5); and individual tube replacement (paragraph 254-2.6.23.6).

254-3.5.12 TUBE-TO-TUBE-SHEET JOINTS. Paragraph 254-2.6.24 gives procedures for expanding tubes into tube sheets.

254-3.5.13 TUBE PLUGGING. Refer to the following paragraphs for tube-plugging procedures: single-tube-sheet heat exchangers with expanded joints (paragraph 254-2.6.26) and temporary plugs for double-tube-sheet units (paragraph 254-2.6.28). Paragraph 254-2.6.29 includes procedures for testing plugged or replaced tubes.

**NOTE**

Some double tubesheet heat exchangers have not been provided with permanent tube plugging tool kits and metal plugs. For those heat exchangers, the use of tapered phenolic plugs by all activities is satisfactory until the unit can be retubed. The applicable equipment manual should be consulted for tube plugging requirements.

254-3.5.14 GASKET REPAIR. Paragraph 254-2.6.31 describes a procedure for repairing leaks in shell flange-to tube-sheet gaskets. This procedure applies only to fixed-tube-sheet heat exchangers with nonremovable tube bundles.

## SECTION 4.

## PLATE HEAT EXCHANGERS

### 254-4.1 ENGINEERING PRINCIPLES AND EQUIPMENT DESCRIPTION

254-4.1.1 GENERAL. Plate heat exchangers use the same principles of heat transfer as do shell-and-tube units, but they are physically quite different. The heat transfer area of a plate heat exchanger consists of parallel plates separated by gaskets. The fluids flow counter-currently in the spaces between the plates, with hot and cold fluids in alternate spaces. Heat thus flows from the hot fluid to the plate by convection, through the plate (and any hot or cold side fouling) by conduction, and to the cold side fluid by convection. Even though the principles are the same as shell-and-tube heat exchangers, the design differences create significant performance differences. Each type has advantages and disadvantages, depending on the application (paragraph 254-4.1.6).

254-4.1.2 COMPONENT DESCRIPTION. Refer to Figure 254-4-1 throughout the following discussion. Although a variety of designs are used by the Navy, this section will deal mainly with the two Navy standard plate heat exchangers (small and large units). Other designs may vary in details, but the basic components and principles are the same. The main components of the Navy standard units are the frames (fixed and movable), guide bars, tie bars, nozzles, plates, gaskets, and shroud. The following paragraphs describe these components.

254-4.1.2.1 Fixed Frame. The frames provide the strength and rigidity necessary for the plate heat exchanger to function properly. The fixed frame at the front of the unit is permanently bolted to the deck, equipment skid, or other foundation structure. This heavy steel frame provides a solid surface against which the plate pack can be tightened. On Navy standard units all inlet and outlet nozzles are also located in the fixed frame. This means that the movable frame and plates can be removed without breaking pipe joints, giving easy access to the plates for cleaning and repair.

254-4.1.2.2 Movable Frame and Guide Bars. The movable frame, also made of heavy steel plate, provides support at the back of the plate pack. As the tie bars are tightened, the movable frame is drawn toward the fixed frame, compressing the plate pack to the proper dimension. The movable frame slides back and forth on upper and lower guide bars. On large units, these guide bars are attached to a support post at the rear of the unit to help carry the weight of the plate pack and movable frame. On small units, the guide bars are self-supporting. The guide bars must be long enough for access to the entire plate pack. When the movable frame has been pulled up to the proper plate pack dimension, a support foot is bolted to the foundation for shock resistance.

254-4.1.2.3 Tie Bars. The tie bars (also called compression, tightening, or tie bolts) connect the movable frame to the fixed frame. When they are tightened, they compress the plate pack between the two frames. The tie bars fit into horizontal slots in the frames or slotted supports welded to the frames, allowing easy removal for access to the plate pack. When tightening or loosening the tie bars, a definite sequence must be followed to ensure even plate pack compression and to prevent plate and gasket damage. This sequence is given in the manufacturer's technical manual or in the PMS cards.

254-4.1.2.4 Nozzles. The nozzles are basically short sections of pipe that direct the fluids into the proper areas of the heat exchanger. They are usually flanged at their outer end for connection to the piping system and project through the frame to contact the gasket on the first plate. Nozzle materials are selected to provide corrosion protection from the fluid they handle. On Navy standard units all four nozzles are in the fixed frame. In some nonstandard cases (such as multipass units or when more than two fluids are involved), the movable frame also has nozzles. This is avoided whenever possible, however, since it requires breaking pipe connections to gain access to the plate pack.

254-4.1.2.5 Plates. The plates and gaskets are the heart of the plate heat exchanger. They guide the fluids and transfer heat between them. The plates are pressed from single sheets of metal (Figure 254-4-2). They vary in size according to heat transfer requirements, but are usually rectangular with about a three-to-one length-to-width ratio. This creates a flow pattern that gives the best heat transfer performance. Most plates have four holes (ports), one in each corner, that act as inlets and outlets for the fluids. Plates are thin (0.024 inch in Navy units) to minimize resistance to heat flow and to help keep unit weight low.

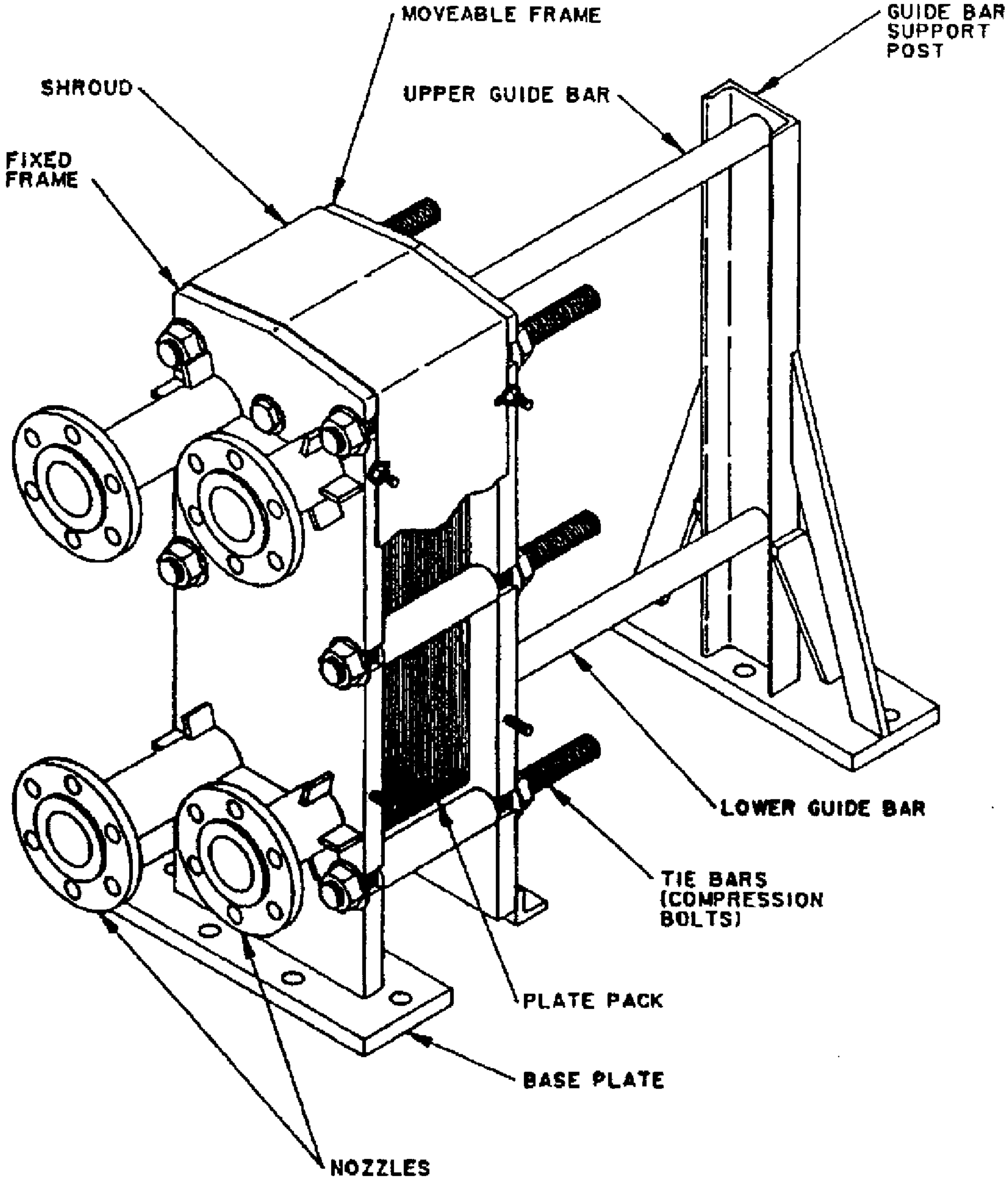



Figure 254-4-1. Plate Heat Exchanger

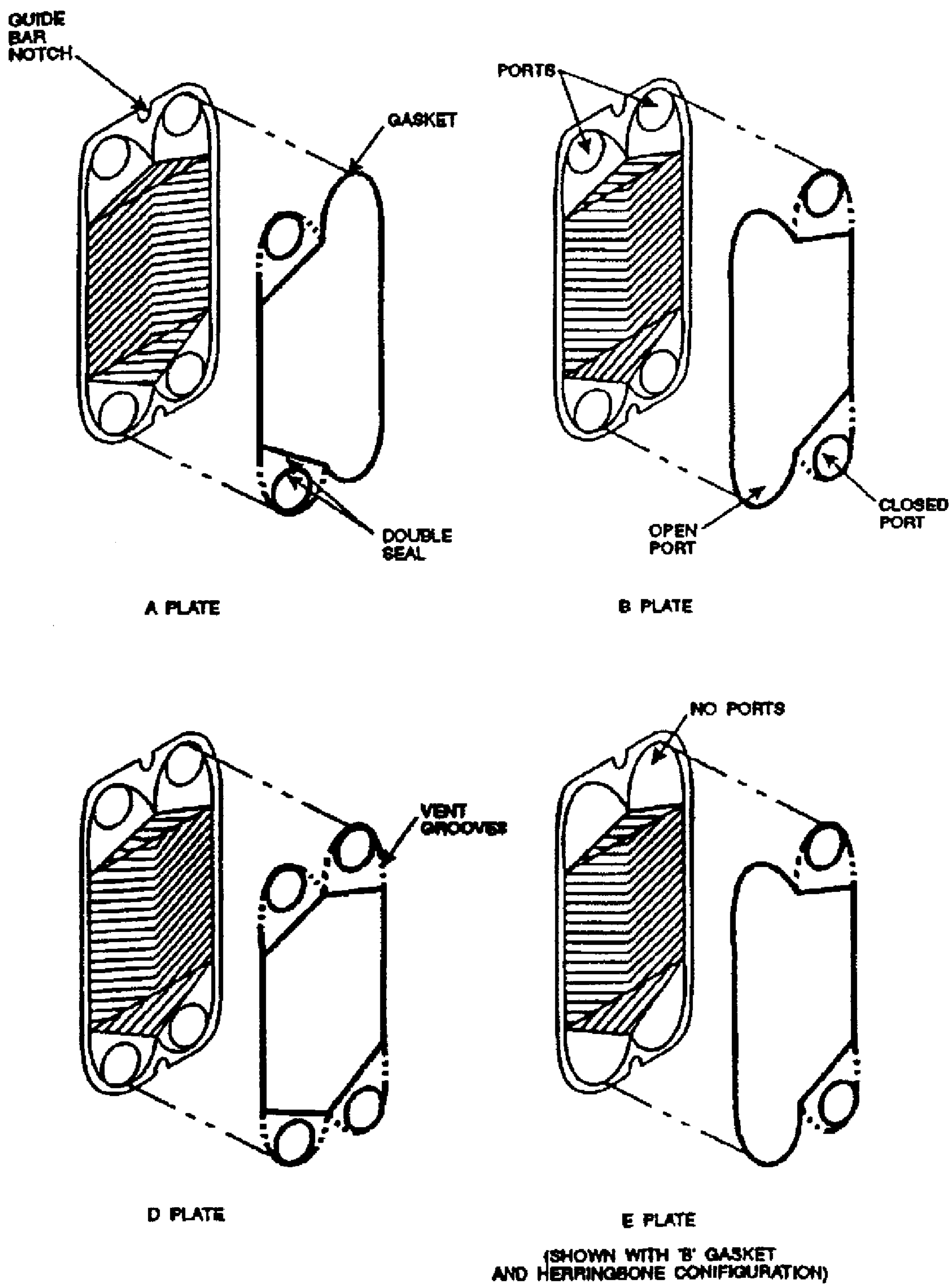



Figure 254-4-2. Plate-Gasket Combinations

254-4.1.2.5.1 During manufacture, herringbone corrugations and flow channels are stamped into the plates, providing structural support, helping distribute the fluids, and increasing heat transfer. Plates can be made of any material that can be formed in a press. Most Navy units use titanium plates for increased corrosion and erosion resistance and weight reduction. For any given unit, all plates (except the last one in the plate pack, next to the movable frame) are identical. The different types of plates discussed in paragraph 254-4.1.4.1 are distinguished by the orientation of the herringbone and gasket pattern.

254-4.1.2.6 Gaskets. Each plate has a gasket that runs around its edge and circles either the hot or the cold fluid inlet and outlet ports. When compressed against the plate in front of it, this gasket prevents fluid from leaking out of the plate pack. It also determines whether hot or cold fluid will flow between the two plates that it separates (depending on which ports are circled and which remain open). The gaskets are glued to grooves pressed in the plate. These grooves ensure that the gaskets are in the proper location and also help to hold them in place when the unit is under pressure. The gaskets are formed from an elastomeric material designed to retain its sealing properties at the operating temperature and pressure. (Gaskets are usually the limiting factor that determine the maximum operating conditions for a plate heat exchanger.)

254-4.1.2.6.1 All gaskets for a given unit are the same. They have an outer portion that follows the perimeter of the plate and they have seals around two of the ports. For the first plate in the pack (located next to the fixed frame and called a D plate), special gaskets that seal all four ports are required. Information on how plates and gaskets are combined into a plate pack is given in paragraph 254-4.1.4.

254-4.1.2.7 Shroud. The shroud is a sheet metal cover that is bolted to the frames after the plate pack has been assembled and pulled up to the proper dimension. It protects the unit from damage (especially the gaskets) and also protects personnel from contact with the hot plate edges and hot fluid in case of leaks.

254-4.1.3 FUNCTIONAL DESCRIPTION. The flow through a plate heat exchanger is controlled by the arrangement of nozzles, plates, and gaskets. Navy standard units operate with two fluids. Each fluid passes counter-currently through the plate pack. Most plate heat exchangers are only effective in liquid/liquid or steam/liquid applications. They lack the ribs or fins required for gas heat transfer.

254-4.1.3.1 Flow Pattern. Both hot and cold fluids usually enter and exit at the front of the heat exchanger. This is not necessarily true for nonstandard units such as those with more than one pass or more than two fluids (paragraph 254-4.1.5). The hot nozzles are on one side of the fixed frame and the cold nozzles are on the other side. If the hot fluid inlet nozzle is at the top right of the unit, for example, then the cold inlet will be at the bottom left. This establishes a counterflow pattern for maximum heat transfer (Figure 254-4-3). The following paragraphs describe in detail a typical path for the hot fluid through a plate heat exchanger. The cold fluid's path will be the reverse. (The actual paths are normally determined by system piping. The critical requirement is that the two paths produce a counterflow arrangement.)

254-4.1.3.1.1 The hot fluid enters the top right-hand nozzle (for example), which extends completely through the carbon steel fixed frame to protect it from corrosion. At the inner end of the nozzle, a lip (seal plate) contacts the gaskets of the first or D plate. (This plate has gaskets around all four ports, preventing either of the two fluids from touching the frame.) The fluid passes out of the nozzle into the plate pack.

254-4.1.3.1.2 In the plate pack, the ports are alined to create four holes that run the entire length of the pack, acting as distribution and return headers. (In most units, the last or E plate has no ports. This protects the carbon steel movable frame from fluid contact.) When the hot fluid enters the plate pack it thus flows along the inlet header, down through the spaces between the plates, and out through the outlet header. The flow area of the interplate spaces is small compared with the port, ensuring that the fluid fills the entire length of the header and flows equally between all plates for maximum heat transfer.

254-4.1.3.2 Fluid Separation and Leak Prevention. As the hot fluid passes through the plate pack, gaskets Figure 254-4-3) direct it into the proper interplate spaces. The ports along each header are alternately either circled by a gasket or open. The fluid thus flows through every other space. On plates with the hot fluid ports open, the cold fluid ports are gasketed so that only one fluid flows in each interplate space. This establishes the alternating hot-cold fluid pattern necessary for heat transfer. For further protection against intermixing, there are always two gaskets between the hot and cold fluids and the void space between the gaskets is open to the atmosphere (Figure 254-4-2). Since both fluids are at some pressure above atmospheric, any leakage into this void space will be forced out of the plate pack rather than into the other fluid. This prevents intermixing and also provides a visual indication of leaks.

254-4.1.3.3 Heat Transfer Enhancement. Plates are installed in the plate pack with the herringbone corrugations in opposite directions for every other plate. This creates interplate spaces with both thick and thin flow areas, producing high velocity and turbulent flow. (One of the benefits of using titanium plates is their erosion resistance, allowing the highest possible fluid velocities.) This type of flow gives high heat transfer rates and also helps to prevent fouling since the turbulent fluids tend to scrub the plates as they pass them. The flow distribution channels stamped into the port areas help to ensure flow across the complete plate area to maximize heat transfer.

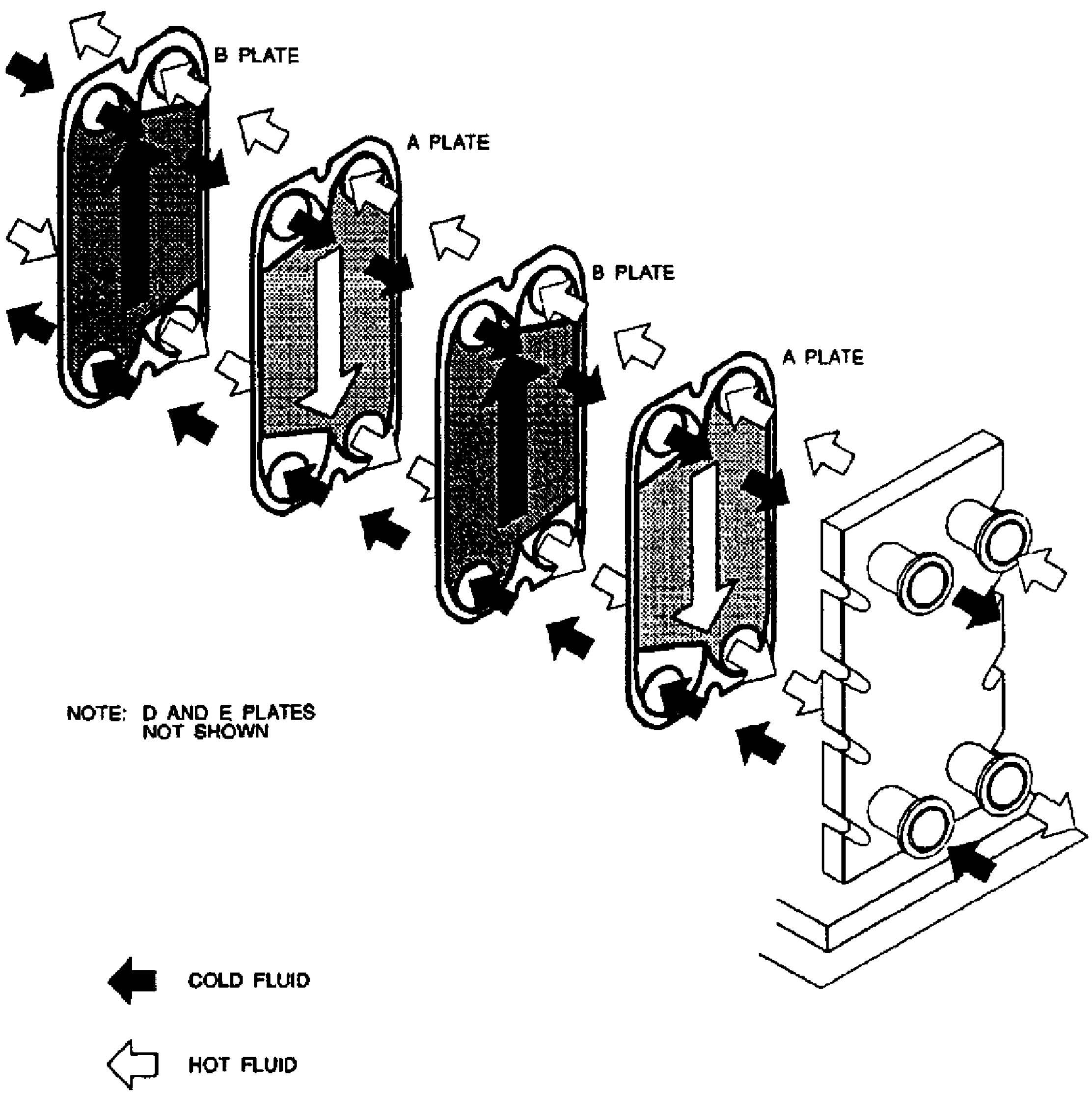



Figure 254-4-3. Plate Heat Exchanger Flow Pattern

254-4.1.4 PLATE PACK CHARACTERISTICS.

254-4.1.4.1 Plate Identification. For Navy standard plate heat exchangers, there are only two different types of plates and two gasket configurations. These are assembled to make the four plate-gasket combinations shown in Figure 254-4-2 and described in paragraphs a through d below. (When this manual or another technical manual calls for a certain plate, such as an A or B plate, it actually refers to a plate-gasket combination and orientation.)

a. A plates have holes at all four port locations, and the herringbones point up. The right-hand ports (viewed from the gasket side of the plate) are open for flow into the interplate space. The left-hand ports have gaskets around them.

b. B plates also have holes at all port locations, and the herringbones point down. The left-hand ports are open for flow, and the right-hand ports are gasketed.

c. D plates have holes at all port locations, and the herringbones point down. D plates have gaskets around all four ports. These gaskets are formed by cutting two standard gaskets in half vertically and using the appropriate parts.

d. E plates are solid at all port locations. The gasket and herringbone configuration will be that of either an A or a B plate.

254-4.1.4.1.1 The descriptions of the A, B, D, and E plates show how the four plate-gasket combinations are assembled from two plates and two gaskets. One plate type (used for A, B, and D plates) has holes at all four port locations, while E plates have no holes. Likewise, one gasket is used for A, B, and E plates, while D plates have a different gasket.

254-4.1.4.2 Plate Arrangement. All Navy standard plate heat exchangers have the same plate arrangement; only the number of plates varies. All plates are installed with the gasket side toward the front of the unit. The first plate installed is a D plate, with its herringbone pattern in a B configuration. The A and B plates are then installed alternately; that is, A-B-A-B and so on throughout the plate pack. This alternating pattern is critical to proper operation of the heat exchanger. A and B plates are actually identical. All that distinguishes an A from a B plate is its orientation; that is, the position of its open ports and the direction of its herringbone pattern. An A plate becomes a B plate (and a B plate an A plate) if it is rotated 180 degrees. The last plate installed is an E plate. Its herringbones should point in the opposite direction from the plate in front of it.

**CAUTION**

**Using the correct plate pack dimension is critical to proper operation of a plate heat exchanger. Over-or under-tightening the tie bolts could cause leaks or plate and gasket damage.**

254-4.1.4.3 Plate Pack Dimension. The plate pack dimension (PPD) is the specified distance between the fixed and movable frames. Accurately maintaining this distance is critical to proper operation of the heat exchanger since the PPD establishes the correct interplate spacing for the desired flow characteristics. This distance also determines gasket compression, which is important for leak tightness and long gasket life. If plates are removed from the heat exchanger, a new PPD must be determined.

254-4.1.5 OTHER PLATE HEAT EXCHANGER TYPES. The discussion so far has been concerned with the Navy standard plate heat exchanger: the two-fluid, single-pass unit. Most plate heat exchangers are of this type. There are other types, however, that may be used on board ships and these are briefly discussed in the following paragraphs.

254-4.1.5.1 Multipass Units. To achieve high heat transfer rates, plate heat exchangers require relatively low fluid velocities. In some cases low flow rates are required by system parameters. Velocities could be increased by reducing the number of plates (and thus the total flow area for each fluid), but this would require increasing the plate length to maintain the available heat transfer surface area. Extremely long, narrow plates are impractical for a number of reasons. A solution to this problem is to have each fluid make multiple passes through the exchanger. A three-pass exchanger, for instance, has one-third the flow area (thus three times the velocity) and the same surface area as a single-pass unit with the same number of plates.

254-4.1.5.1.1 Multipass units use special plates to create the passes. These plates lack holes at appropriate port locations, preventing the fluids from flowing all the way through the exchanger along a single header. A three-pass unit would have special plates one-third and two-thirds of the way through the plate pack. The hot fluid might enter at the top and flow down through the first third of the plate pack. It would then flow up through the middle third, down through the last third, and exit at the bottom of the movable frame. This illustrates one disadvantage of multipass units. Because each fluid's inlet and outlet nozzles must be at opposite ends of the exchanger, nozzles are required in the movable frame, which means breaking these piping connections for inspection or maintenance.

254-4.1.5.2 Three-Fluid Units. Some plate heat exchangers handle three fluids at once. One fluid (seawater, for example) will flow through every other space throughout the entire plate pack, just as in a single-pass, two-fluid unit. Some of the remaining spaces will be filled by a hot fluid entering and leaving through the fixed frame. A special plate with blocked ports at the appropriate locations will prevent this fluid from flowing through the entire unit. The other hot fluid, which enters and exits through the movable frame, fills the remaining spaces. The special plate thus acts as a barrier to separate and direct the flow of the two hot fluids. The number of flow channels for each hot fluid is determined by the placement of the special plate. Using an E plate in the middle of the plate pack would allow four different fluids to flow through the heat exchanger. Three-fluid units are relatively rare and four-fluid units are even less common. These exchangers have the same disadvantage as multipass units: they require nozzles in both the fixed and the movable frame.

254-4.1.6 COMPARING HEAT EXCHANGER TYPES. Shell-and-tube and plate heat exchangers each have advantages and disadvantages. The best type for a particular application will depend on several factors.

254-4.1.6.1 Size and Weight. Most plate heat exchangers are much smaller than shell-and-tube units designed for the same service. The counterflow, high-turbulence design of the plate units makes them very efficient, allowing them to transfer a given amount of heat with the minimum surface area. This small size and the thinness of the plates (compared with tube walls) also keeps weight to a minimum. The size and weight advantage of plate heat exchangers is greatest for large units. For very small units, the weight and size of the steel frames and support structures are such that plate heat exchangers may actually be larger and heavier than shell-and-tube exchangers.

254-4.1.6.2 Temperature and Pressure Limits. Through proper material selection and component sizing, shell-and-tube heat exchangers can be designed to operate at any reasonable temperature or pressure. Plate heat exchangers, however, are limited by the gasket material, which must retain its elastomeric properties for proper sealing. At high temperatures these materials have shortened lives or break down completely. Also, excessive pressure will push the gasket out of its retaining groove, causing leaks. Currently, the highest fluid temperature and pressure at which plate heat exchangers can operate are 350 degrees F and 350 psig. The Navy standard units are designed for continuous operation at no more than 200 degrees F and 180 psig.

254-4.1.6.3 Maintenance. In general, plate heat exchangers are easier to maintain (paragraph 254-4.3). Units can be opened for inspection, cleaning, or repair without breaking piping connections (if all nozzles are on the fixed frame). Most maintenance procedures, such as cleaning or gasket replacement, also tend to be easier since the plates are readily accessible and can even be removed if necessary. A disadvantage of plate heat exchangers is that they are more sensitive to clogging than shell-and-tube units. Interplate spaces are much smaller than tube inside diameters. Seaweed or other foreign material can therefore clog flow passages more readily and thus remove large areas of heat transfer surface from service. For this reason, backflushing (paragraph 254-4.3.4) is periodically required for seawater-cooled plate heat exchangers.

## 254-4.2 OPERATION

254-4.2.1 GENERAL. Like shell-and-tube units, most plate heat exchangers are passive devices; that is, they have no controls (other than inlet and outlet valves) and require no actual operation. Any specific operating procedures that are required (such as controlling one or both flows to maintain the proper temperatures and pressures) depend on the system served by the heat exchanger and are not discussed here.

254-4.2.2 EMERGENCY OPERATION. Whenever possible, operate the heat exchanger with the correct number of plates. If gaskets are damaged, shut down the unit and replace the affected gaskets (paragraphs 254-4.3.2, 254-4.3.6, and 254-4.3.8). If replacement gaskets are unavailable or the plates are damaged, however, the unit can be operated with a reduced plate pack using the following procedure:

1. Only A and B plates can be removed. Never operate without properly gasketed D and E plates at the front and rear of the plate pack.
2. When the defective plate or gasket has been located, remove it and an adjacent plate. Always remove plates in A-B pairs to retain the countercurrent (alternating hot-cold) flow pattern.

**CAUTION**

**Never operate a plate heat exchanger unless the PPD for the specific number of plates installed has been determined. Operating with the wrong PPD could cause leaks or plate gasket damage.**

3. When plates have been removed, calculate a new PPD. The manufacturer’s technical manual or the Planned Maintenance System (PMS) cards have a table that relates plate number to PPD.
4. Closely monitor fluid temperatures and pressures to make sure that reducing the plate pack has not adversely affected system operation.

### 254-4.3 MAINTENANCE

254-4.3.1 GENERAL. This section is not intended to replace the detailed maintenance procedure found in most plate heat exchanger technical manuals. When these manuals are available, follow their procedures. If technical manuals are unavailable or incomplete, the following paragraphs give general guidelines for maintaining plate heat exchangers.

**WARNING**

**Never tighten or loosen the plate pack while the unit is operating, under pressure, full of water, or hot. This could cause serious injury and plate or gasket damage.**

**CAUTION**

**To avoid plate or gasket damage from water hammer, decrease the pressure of both fluids gradually and simultaneously.**

**NOTE**

Do not paint the plate or gasket edges. This could clog the gasket vent grooves and hinder leak detection.

254-4.3.2 SHUTTING DOWN FOR MAINTENANCE.

1. Gradually close both inlet valves, then close both outlet valves.
2. Shut down the pumps, and close the inlet valve to the duplex strainer (if installed).
3. Open the drains.
4. If the inlet and outlet connections have vents, open them to ensure proper drainage.
5. Check the inlet and outlet pressure gages to make sure the unit is not under pressure.
6. Allow the heat exchanger to cool to room temperature before opening it. Opening a hot plate heat exchanger may loosen or damage the gaskets.

254-4.3.3 PLATE HEAT EXCHANGER LAY-UP. If plate heat exchangers are to be idle for less than 3 months, vent and drain as described in paragraph 254-4.3.2. If units are to be idle for 3 months or longer, or if freezing is possible during the idle period, lay up the heat exchanger according to the following procedure:

1. Drain and vent the heat exchanger as described in paragraph 254-4.3.2.
2. Remove the shroud.
3. Remove the foundation bolts from the movable frame and loosen the adjustable bolt.

4. Loosen all tie bolts using the same loosening sequence as for disassembly (paragraph 254-4.3.6). Continue to loosen until the PPD has increased by 20 percent. This will relieve the pressure on the gaskets and prevent them from being permanently compressed.

254-4.3.4 BACKFLUSHING. Since plate heat exchangers contain smaller flow passages than shell-and-tube units, they are more sensitive to accumulations of seaweed and other material. All seawater-cooled plate heat exchangers with the appropriate piping connections (Figure 254-4-4) should therefore be backflushed periodically. Backflushing, which is only required for seawater cooled units, is not done according to a set schedule. Backflushing is needed when the pressure drop through the unit increases by 10 psi (compared with a clean unit). The following procedure is recommended for backflushing:

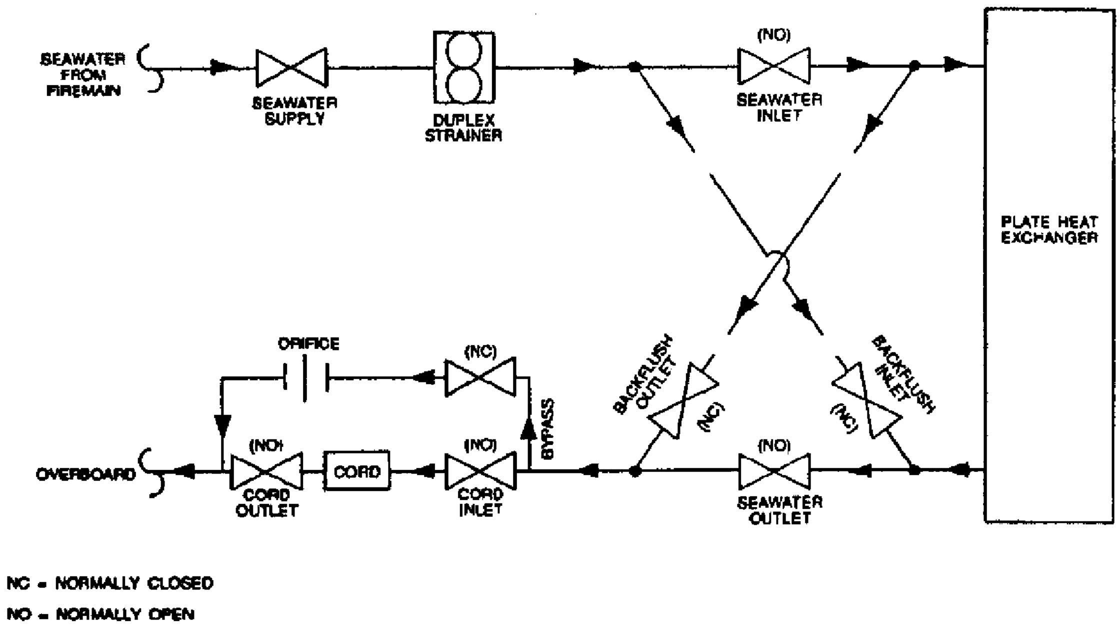



Figure 254-4-4. Backflushing Piping Arrangement

1. If the unit has a Cascading Orificial Restrictive Device (CORD) downstream from the seawater outlet, bypass the CORD before backflushing. Shut the CORD inlet and outlet valves and open the CORD bypass valve. If the CORD is not bypassed, it may become clogged, requiring disassembly and cleaning.

2. Gradually close the seawater inlet and outlet valves.

3. Gradually open the backflushing inlet and outlet valves, and backflush for 15 minutes.

4. When backflushing is completed, gradually close the backflushing valves, slowly open the seawater inlet and outlet valves, and restore the CORD to normal operation.

**NOTE**

Backflushing is only necessary for the seawater side of the unit. No adjustments need to be made in the hot fluid flow.

254-4.3.5 LEAK DETECTION. Leaks can be caused by defective or damaged gaskets, overpressurization, misalined or reversed plates, or plate pack undertightening or overtightening (resulting in crushed or cocked plates). Most plate heat exchanger leaks occur at the gaskets, but they occasionally occur at cracks or holes between the plates. The following paragraphs give procedures for finding leaks.

254-4.3.5.1 Gasket Leaks. If drips from under the shroud or other evidence of leakage is seen, use the following steps before disassembling the unit for leak detection and repair:

1. Shut down and drain the heat exchanger as described in paragraph 254-4.3.2.
2. Check that the plate pack is tightened to the PPD shown in the heat exchanger technical manual or in the PMS cards.
3. Return the system to normal operation and recheck for leaks. If leakage has stopped, no further action is required.
4. If leakage has not stopped, inspect the operating unit for the leak location. If the leak is clearly visible, note its location and proceed with the repair (paragraph 254-4.3.8).
5. If the leak location is not obvious, completely dry the plate pack exterior and examine it carefully with a flashlight until the leak is found. On large units it may be necessary to repeat the drying several times. Note the leak location and proceed with the repair (paragraph 254-4.3.8).

254-4.3.5.2 Plate Leaks. Plate holes or cracks are rare but they do occur. This type of leak will show up as a loss or contamination of one or both of the fluids. Investigate all other possible sources of this loss or contamination before checking for plate leaks. If the source of the leakage has been confirmed to be the plate heat exchanger, use the following procedure to locate the leaks:

1. Shut down and drain one side of the heat exchanger (either the hot or the cold fluid) as described in paragraph 254-4.3.2. Close the outlet valve on the other side of the heat exchanger but do not shut off the flow to the unit. This will leave the unit with every other flow channel filled with pressurized fluid.
2. Remove the piping connections from the lower nozzle on the drained side.
3. Observe the open nozzle long enough to determine whether any fluid is flowing from it. (This could take up to 1 hour for small leaks.) If there is no fluid, the leak is elsewhere in the system. If leakage is detected, continue with this procedure to locate the leaking plates.
4. Shut down and drain the other side of the heat exchanger as described in paragraph 254-4.3.2. Disassemble the unit (paragraph 254-4.3.6), and clean the plates (paragraph 254-4.3.7). Thoroughly dry both sides of all plates and reassemble the unit as described in paragraph 254-4.3.9.
5. Close the outlet nozzle on the previously pressurized side and restart flow to this side. Do not restart flow to the side with the disconnected piping.
6. Leave the unit under pressure until the leak can be seen. If possible, look into the open nozzle and measure the distance to the leak to determine its approximate location.
7. Shut down, drain, and disassemble the heat exchanger. Inspect the sides of the plates facing the dry flow spaces. If fluid is found in any of these dry spaces, one of the two plates facing it leaks. Carefully examine the suspect plates to determine which one is leaking. Hold the plates up to a light to aid leak location. Very small leaks may require dye penetrant inspection.
8. If replacement plates are available, replace the defective plate and reassemble the heat exchanger (paragraph 254-4.3.9). Always replace with the same type of plates (A or B). If replacements are unavailable, remove two plates as described in paragraph 254-4.2.2.

254-4.3.6 DISASSEMBLY. Disassemble the heat exchanger unit as follows:

1. Shut down and drain the heat exchanger as described in paragraph 254-4.3.2.
2. Remove the foundation bolts from the movable frame base plate and loosen the adjustable bolt.
3. Loosen and remove the tie bolts in the proper sequence given in the heat exchanger technical manual or in the PMS cards.
4. Slide the movable frame away from the plate pack. Carefully separate the plates and slide them toward the rear of the unit, starting from the back of the plate pack.
5. Whenever possible, inspect or clean the plates in place. This will help prevent plate or gasket damage.
6. If it is necessary to remove the plates, tilt them toward the rear of the unit until the top slot is free of the guide bar, and lift them out.
7. Always lay removed plates on a clean, flat surface where they will not be stepped on or otherwise damaged.

254-4.3.7 CLEANING. Cleaning is not done according to a set schedule, but rather when a drop in performance indicates it is necessary. When the specified performance cannot be restored by backflushing, clean the heat exchanger according to the following procedure:

1. Shut down, drain (paragraph 254-4.3.2), and disassemble (paragraph 254-4.3.6) the unit.
2. If only minor cleaning is required, clean the plates in place by sliding them apart one at a time. If fouling is heavy, remove the plates and lay them on a clean, flat surface.

**CAUTION**

**Never use a steel brush or steel wool to clean the plates. This could scratch the plates and damage the gaskets.**

3. Clean the plates with a fiber brush and clean water. Be careful not to damage or loosen the gaskets.
4. After cleaning, rinse the plates. Wipe the gasket areas dry on both sides of the plate and check to make sure that there is no debris in the gasket areas.
5. Reassemble the unit (paragraph 254-4.3.9).

254-4.3.8 GASKET REPLACEMENT. When the approximate location of a gasket leak has been determined (paragraph 254-4.3.5.1), carefully inspect the nearby plates for gasket damage. When the damaged gasket is found, replace it according to the following procedure:

1. Lay the plate on a clean, flat surface. Note the position of the gasket on the plate (that is, which grooves are filled and which are empty).
2. Insert a screwdriver under the gasket and pry the gasket up far enough to insert a finger. Slowly pull on the gasket until it is completely removed.

**WARNING**

**Solvents contain harmful or flammable vapors. Use them only at normal temperatures in well ventilated areas. Make sure the vapors are not exposed to open flames, sparks, or electric motors.**

**CAUTION**

**Do not use torches, grinding wheels, or steel brushes to remove adhesive residue. These tools can damage the plates.**

3. Remove all adhesive residue, oil, grease, and any other foreign material from the gasket groove. Use solvents such as methylethyl ketone (MEK), acetone, other ketones, or commercial paint stripping compounds for this task. Apply the solvent with a nylon brush.

4. When the groove is clean, wipe it dry with a clean cloth.

**CAUTION**

**Do not use hardening adhesives on plate heat exchanger gaskets. They can interfere with proper operation and will make the gasket difficult to remove.**

5. Apply the adhesive to the proper gasket grooves. The recommended adhesive is Pliobond 30 or equal. Pliobond 20 or equal can also be used.

6. Lightly position the gasket on the plate so that it lies in the groove all the way around. Make sure that the gasket code number and the bleed recess (both of which are in the bleed passage area) are facing up. If they are not visible, the gasket is upside down.

7. Using finger pressure, press the gasket firmly into place.

8. Place a weighted sheet of plywood on the plate to compress the gasket while the adhesive dries. Allow at least 12 hours curing time at room temperature for adequate adhesion. If several plates are gasketed at once, stack them on top of each other and place the weighted plywood sheet on top of the stack.

9. When the adhesive has cured, remove any excess on the plate or gasket face with a solvent. Make sure the plate and gasket are clean and dry and reinstall the plate into the plate pack.

254-4.3.9 REASSEMBLY. Reassemble the heat exchanger unit as follows:

1. Wipe the gaskets and mating plate surfaces dry with a cloth.

2. Reinstall any removed plates into the plate pack. Tilt the plate until it fits between the guide bars and drop the lower notch over the lower guide bar. Push the plate upright and toward the front of the unit until it contacts the plate pack. Make sure that the gasket mates properly with the plate in front of it.

3. When all the plates are in place, slide the movable frame against the plate pack and install the tie bolts.

**CAUTION**

**Do not tighten the plate pack beyond the PPD. Plate or gasket damage could result.**

4. Tighten the tie bolts in the sequence shown in the manufacturer's technical manual and in the PMS cards. Continue tightening until the PPD is reached.

5. Tighten the adjustable bolt and reinstall and tighten the foundation bolts into the movable base plate.

6. Reinstall the shroud.

254-4.3.10 TROUBLESHOOTING GUIDE. Table 254-4-1 lists typical plate heat exchanger problems and possible causes and solutions.

**Table 254-4-1** PLATE HEAT EXCHANGER TROUBLESHOOTING GUIDE

| Problem | Probable Cause | Solution |
|---|---|---|
| a. Insufficient flow | 1. Fouled plates | 1. Clean plates (paragraph 254-4.3.7). |
| | 2. Pump malfunctions | 2. Check flow rate per technical manual, correct as required. |
| | 3. Strainer plugged | 3. Clean strainer. |
| b. Insufficient cooling | 1. Fouled plates | 1. Clean plates (paragraph 254-4.3.7). |
| | 2. Coldside flow too low | 2. Check flow rate per technical manual, correct as required. |
| c. Leaks through gaskets | 1. Frame not tight enough | 1. See paragraphs 254-4.1.4.3 and 254-4.3.9on tightening the plate pack. |
| d. Internal leaks | 1. Crack in a plate | 1. See paragraph 254-4.3.5.2 on finding a defective plate |
| e. Fouled plates | 1. Extended period in port | 1. See paragraph 254-4.3.7on cleaning plates. |

## SECTION 5.
## AIR EJECTORS AND AIR EJECTOR CONDENSERS

### 254-5.1 USES

254-5.1.1 GENERAL. Air ejectors or vacuum pumps remove the noncondensable gases (mainly air) that leak or are discharged into condensers operating under vacuum. They also compress these gases to the pressure necessary to discharge them from the condensing system.

254-5.1.2 SHIPBOARD USES. Shipboard air ejectors normally serve the main condenser of the main propulsion units, the auxiliary condenser of the turbogenerators, the distiller condenser of low-pressure distilling plants (NSTM Chapter 531, Volume 1, Desalination) , and, on a few large ships, the heating unit drain collecting system(NSTM Chapter 255, Volume 1, Feed and Condensate Systems) . In some cases air ejectors are also used as eductors to remove the steam-air mixture from the turbine glands.

## 254-5.2 ENGINEERING PRINCIPLES

254-5.2.1 NOZZLE. High-pressure motive steam is fed to the nozzle inlet (Figure 254-5-1). In passing through the nozzle, the steam's pressure is dissipated as it accelerates to a high velocity when it exits the nozzle throat. The high-velocity, low-pressure jet of steam from the nozzle entrains the steam-air mixture entering the ejector from the condenser. This tends to draw more air into the ejector, resulting in a continuous removal of air from the condenser.

254-5.2.2 DIFFUSER. The steam and air mix as they pass from the nozzle to the diffuser. The divergent section at the downstream end of the diffuser decreases the velocity of the moving mixture while increasing its pressure and thus converts the velocity (kinetic) energy into pressure energy. Air and other noncondensable gases removed from the condenser are therefore compressed.

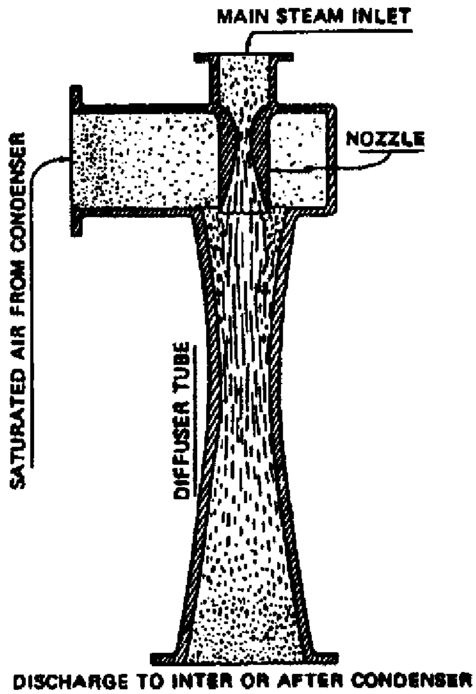



Figure 254-5-1. Single-Stage Air Ejector Schematic

## 254-5.3 EQUIPMENT TYPES

254-5.3.1 SINGLE-STAGE EJECTORS. The air ejector element shown in Figure 254-5-1 is a single-stage ejector. This type is generally used for low-pressure distilling plants.

254-5.3.2 MULTISTAGE EJECTORS. Two-stage ejectors are generally used for condensers serving turbines so that high vacuum may be obtained economically. A second air ejector element is placed in series with the primary air ejector element. The first-stage air ejector compresses the steam and air to an intermediate pressure. The second-stage element provides final compression to atmospheric pressure or slightly above so that air and other noncondensable gases can be vented to the atmosphere.

254-5.3.2.1 Single-stage ejectors are unsuited for operation at condenser vacuums higher than about 27 inches of mercury. All high-vacuum ejectors thus use two- or three-stage ejector elements in series. Three-stage ejectors are normally not used by the Navy because they are mechanically complicated and because two-stage ejectors are capable of evacuating condensers to a vacuum higher than most naval turbine and condenser installations require.

254-5.3.2.2 In most naval air ejector installations, two single- or two-stage air ejector elements are used in each air ejector assembly. One set of elements handles air leakage under all normal condenser operating conditions. A second single- or two-stage element acts as a standby unit. This standby unit is also used in parallel with the other unit for temporary operation when excessive air leaks into the vacuum system.

254-5.3.2.3 Some air ejector assemblies have three two-stage elements in parallel. With a tight vacuum system, any one of the three sets of elements provides sufficient air removal for the condensing plant. Air leakage somewhat greater than normal requires using two of the two-stage ejector units in parallel, with the third unit acting as a standby.

254-5.3.2.4 Some installations have two sets of ejector elements of unequal capacity. The smaller ejector is used when the vacuum system is free of excessive air leakage. The larger ejector is used when air leakage into the vacuum system exceeds the capacity of the smaller elements.

254-5.3.2.5 In most naval installations the need to operate more than one pair of elements of a two-stage ejector assembly to maintain proper condenser vacuum and minimum condensate depression indicates excessive air leakage into the vacuum system. Take steps to eliminate the air leaks ( paragraph 254-2.6.20.)

254-5.3.3 RADOJET AIR EJECTORS. Some old installations use a radojet air ejector with an adjustable second-stage nozzle. Other types of air ejectors have no corresponding adjustment. Frequently, no intercondenser is provided and the second-stage radojet element handles the first-stage motive steam and the air pumped from the condenser.

254-5.3.4 AIR EJECTOR CONDENSERS. The steam-air mixture discharged from an ejector is normally condensed in a shell-and-tube condenser. For single-stage ejectors used with low-pressure distilling plants, this steam is condensed in an air ejector condenser (NSTM Chapter 531, Volume 1). For two-stage air ejector assemblies, ejector elements are generally mounted on condensers as shown in Figure 254-5-2 and Figure 254-5-3.

254-5.3.4.1 Inter- and After-Condensers. The steam-air mixture is discharged from the first-stage ejector element into the inter-condenser where the steam content of the mixture is condensed (figure 254-5-3). The remaining saturated air is drawn into the second-stage ejector element, which discharges the air and the second-stage ejector motive steam into the after-condenser. The steam content of the mixture is condensed in the after-condenser, and the saturated air passes through the after-condenser vent to the atmosphere.

254-5.3.4.2 Cooling Water. Condensate from the condenser served by the air ejector is normally used as the cooling medium for condensing the steam in air ejector inter- and after-condensers. Some inter- and after-condensers, however, are seawater or freshwater cooled (NSTM Chapter 255, Volume 1). The amount of steam to be condensed is very nearly constant regardless of whether the condenser is operating at high or low capacity. To provide sufficient condensate cooling water for the air ejector assembly when the condenser is operating at low capacity or in standby, additional water must be supplied to the condenser through recirculation (NSTM Chapter 255, Volume 1) to augment the condensate available from the small quantity of steam being condensed.

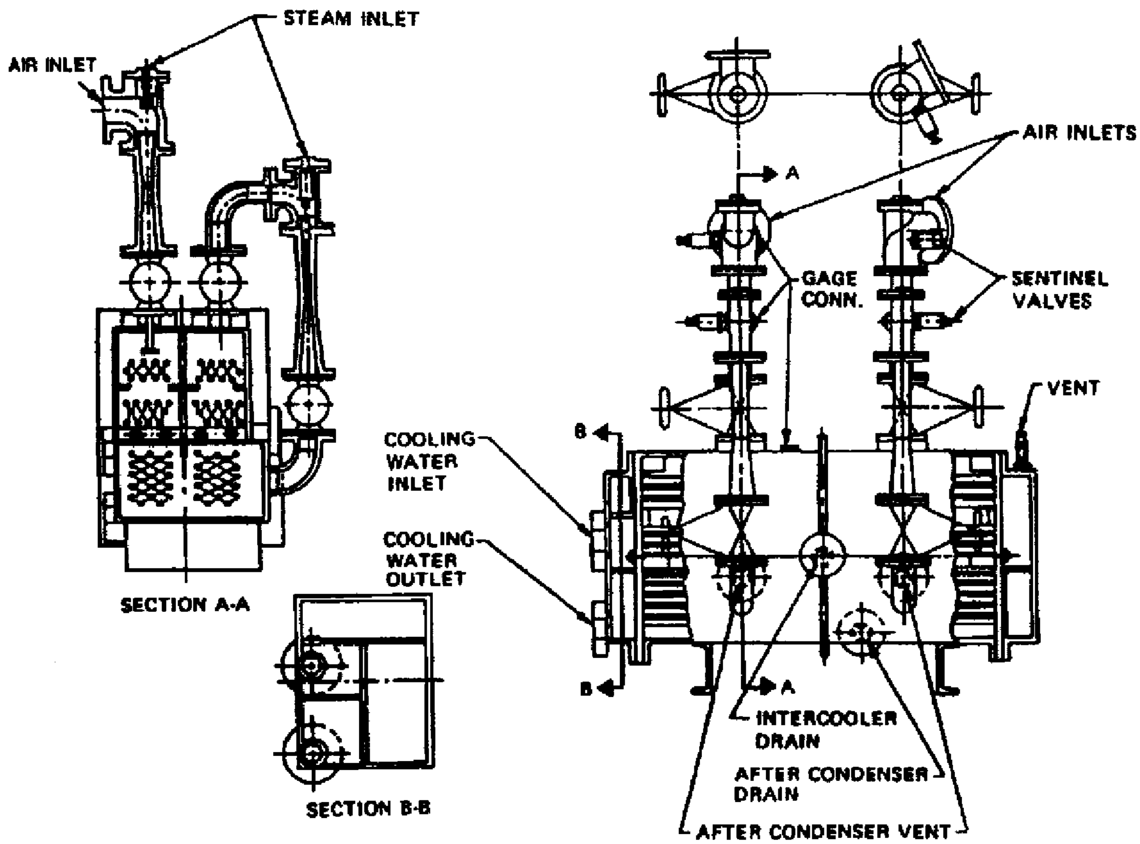



Figure 254-5-2. Twin-Stage Air Ejector

254-5.3.4.3 Drains. The steam condensed in the air ejector inter- and after-condensers returns to the ship's feed system to conserve feedwater. The drain from the inter-condenser returns to the condenser served by the air ejectors through a U-shaped loop seal. This seal must be long enough to balance the maximum vacuum differential existing between the inter-condenser and the condenser being served. The column of water in the leg of this seal open to the condenser must prevent noncondensable gases (drawn from the condenser by the first-stage ejector element) from discharging directly back to the condenser through the inter-condenser drain. Such a discharge would reduce the effectiveness of the first stage in removing air from the condenser. For the inter-condenser to drain properly on air ejector startup, the assembly is generally mounted 2 feet or more above the condenser. This provides gravity drainage before a vacuum differential is built up. The steam condensed in the after-condenser drains to the low-pressure drain collecting system.

254-5.3.4.4 Gland Steam Condensers. In some main condenser air ejectors a gland steam condenser is built into the air ejector inter- and after-condenser assembly (Figure 254-5-3). The steam-air mixture removed from the main turbine glands is discharged to this condenser where the steam content of the mixture is condensed and residual air is vented to the atmosphere. A gland exhauster fan is generally provided in the vent discharge line to draw vapor from the turbine glands through the system. In some installations, a single-stage ejector unit is provided, instead of the gland exhauster fan, to pump vapor through the system and an additional condensing section is provided to condense the steam discharged from this unit. Gland exhaust condenser vent and drain connections are generally separate from the after-condenser vent and drain, although in some installations they are combined. Cooling water for the gland exhaust condenser is usually connected in series or in parallel with condensate cooling the air ejector after-condenser.

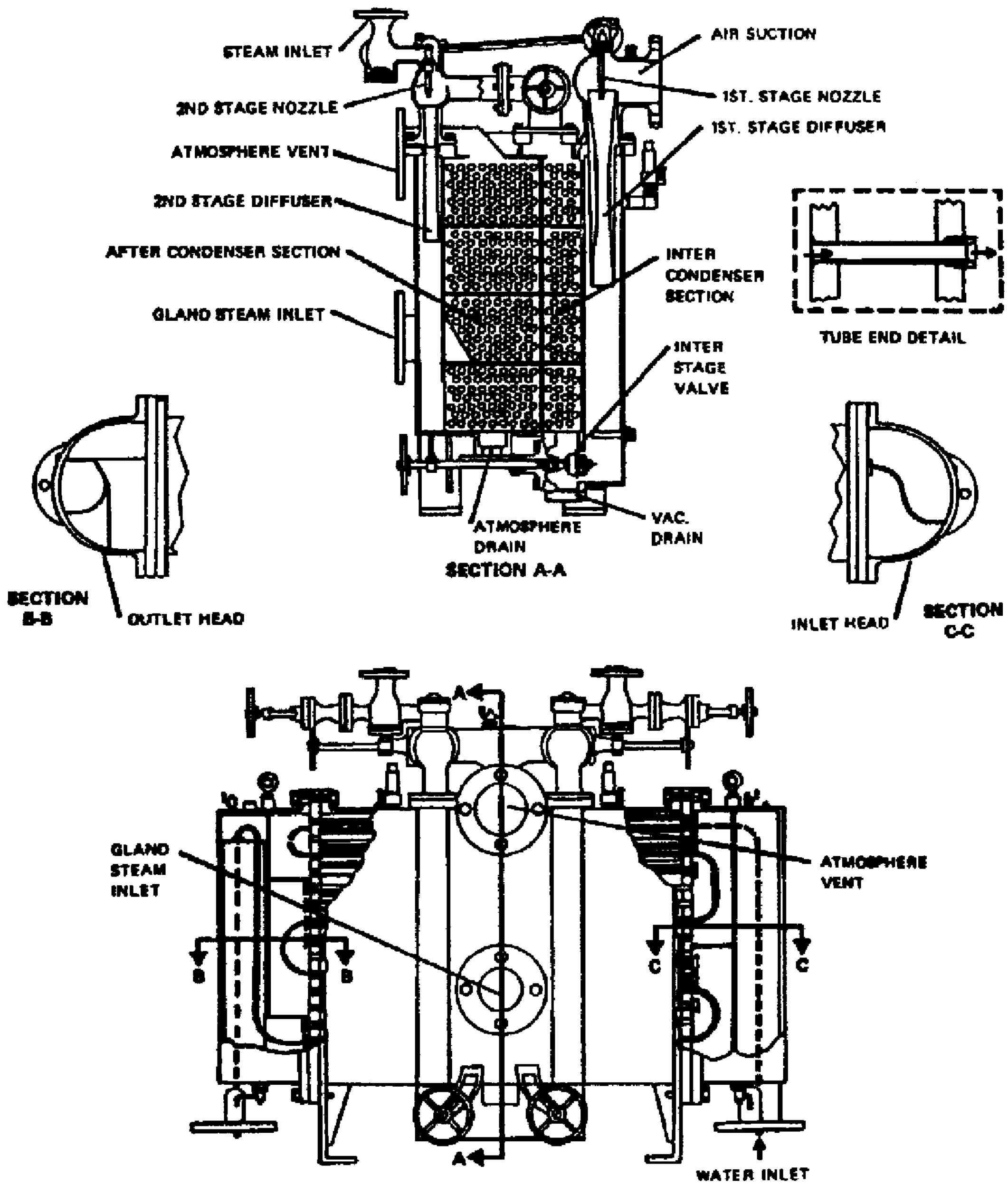



Figure 254-5-3. Twin Two-Stage Air Ejector with Integral Gland Steam, Inter- and After-Condensers

254-5.3.5 STEAM STRAINERS. Steam strainers are always provided ahead of air ejector nozzles to keep the nozzles from becoming coated or clogged with foreign material. Strainers are usually basket type, with the steam flow directed to the inside of the strainer basket.

254-5.3.6 SENTINEL VALVES. Air ejector diffusers are not designed to withstand operating steam pressure. If proper operating procedures are not followed an explosion is possible. Sentinel or relief valves (Figure 254-5-2) are generally provided to warn operators of interstage valve maloperation. Do not rely on these as a substitute for proper operating practice. Even though excessive pressure may not cause an explosion, extra maintenance work will probably be necessary to replace blown gaskets.

254-5.3.6.1 Some twin two-stage air ejectors have separate inter- and after-condensers. In such cases interstage isolating valves are usually omitted and sentinel valves are sometimes installed on the inter-condenser shells instead of on the diffusers. Unless the order of opening and closing valves is carefully followed, excessive pressure could be applied to the inter-condensers and diffusers. The sentinel and relief valves are generally arranged with a water seal for use in testing valve tightness.

## 254-5.4 OPERATING PRINCIPLES

254-5.4.1 STARTING. The general procedure for starting air ejectors is as follows:

1. Drain the steam supply lines to the air ejector assembly.
2. Start circulating condensate cooling water through the air ejector inter- and after-condenser, and vent the waterboxes. (Recirculating condensate to the condenser will be necessary to provide sufficient cooling water.)
3. Open and fill the inter-condenser loop seal drain line to the main condenser and the drain line from the after-condenser.
4. Check that the pressure and vacuum gage line valves are open and that the after-condenser atmospheric vent line is clear. (Before starting, drain any pockets where moisture could collect in the vent line. Keep the vent line clear of condensate during operation.)
5. Open the first- and second-stage suction and discharge valves of the air ejector elements to be started.
6. Open wide the second-stage ejector steam inlet valve. Check that the steam supply line pressure is at or above the recommended operating pressure. (Operating pressure is stamped on the nameplate of the air ejector assembly.)
7. Open wide the steam supply line valve to the first-stage ejector element when the condenser vacuum rises to at least 20 inches of mercury.

254-5.4.1.1 After completing the starting procedure, the ejector assembly should be fully operating. The main condenser vacuum should rise rapidly to that usually obtainable under standby conditions. To raise the vacuum more quickly, both second-stage elements of an ejector assembly may be started simultaneously, and both first-stage elements may be started when a vacuum of at least 20 inches of mercury is attained.

254-5.4.1.2 Adequate recirculation is necessary to condense the additional steam discharged to the air ejector condensers. No gain in speed is achieved by starting the first-stage elements before the condenser vacuum has risen to 20 inches of mercury. When the maximum vacuum attainable has been reached in the condenser, take the extra two-stage elements out of service by closing these valves in the following order:

1. First-stage ejector suction valve.
2. First-stage ejector steam inlet valve.
3. Second-stage ejector suction valve.
4. First-stage ejector discharge valve (if provided).
5. Second-stage ejector steam valve.
6. Second-stage ejector discharge valve (if provided).

254-5.4.2 SECURING. The procedure for securing air ejectors is as follows:

1. Close the first-stage suction valve.
2. Close the first-stage steam inlet valve.
3. Close the second-stage suction valve.
4. Close the first-stage discharge valve (if provided).
5. Close the second-stage steam valve.
6. Close the second-stage discharge valve (if provided).
7. Leave the drain lines open so the pressure will not build up if a steam inlet valve leaks. If steam backs up through the after-condenser drain line when the unit is secured, the drain may be closed after determining that the steam inlet valve is tight and that the sentinel and relief valves on the air ejector assembly are operating properly.

254-5.4.3 SHIFTING EJECTOR ELEMENTS. If it is necessary or desirable to shift from one two-stage ejector to another while the air ejector is operating, use the following procedure:

**CAUTION**

**If insufficient cooling water is provided or if the valves are opened and closed in the wrong order, vacuum will be lost and the air ejector condensers and diffusers may be subjected to excessive pressure.**

1. Open the second-stage ejector discharge valve (if provided) of the standby unit and make sure that the after-condenser drain line is clear (if a separate after-condenser and drain are provided).
2. Open wide the second-stage steam inlet valve of the standby unit.
3. Open wide the second-stage suction valve. The standby second-stage unit will begin to take suction from the inter-condenser.
4. Open the standby first-stage discharge valve (if provided) and make sure that the inter-condenser drain valve is open (if a separate inter-condenser and drain are provided).
5. Open wide the steam inlet valve to the standby first-stage nozzle.
6. Open wide the suction valve of the standby first-stage element. At this point both two-stage elements are operating in parallel.
7. Close the suction valve of the first-stage element to be secured.
8. Close the steam supply valve to the first-stage element to be secured.
9. Close the suction valve of the second-stage element to be secured.
10. Close the discharge valve (if provided) of the first-stage element to be secured.
11. Close the steam supply valve of the second-stage element to be secured.
12. Close the discharge valve (if provided) of the second-stage element to be secured.

254-5.4.3.1 This completes the shifting operation. If the condenser is operating at low or medium capacity when the elements are shifted, it may be necessary to increase the recirculation to the condenser during the time when both two-stage elements are in service. This will provide sufficient cooling water for the inter- and after-condensers.

254-5.4.4 SAFETY FACTORS. Do not operate an air ejector above its rated capacity, pressure, and temperature. This will subject it to stresses and strains it was not designed to withstand.

254-5.4.4.1 Before starting an air ejector, always drain the steam supply line. Open the drain valves in the inter- and after-condenser drain lines and make sure that the atmospheric vent line is clear.

254-5.4.4.2 When starting an air ejector, always open the interstage valves before admitting steam to the nozzles. When securing, always tightly close the steam supply valves to the nozzles before closing the interstage standby valves.

**WARNING**

**When overhauling one set of air ejectors while another set is operating, make sure that all isolating valves are securely closed to prevent burns to personnel.**

254-5.4.4.3 Take extreme care to prevent damage to internal surfaces when removing a nozzle or diffuser from an air ejector.

254-5.4.4.4 Maintenance safety precautions for air ejectors are integrated into the specific maintenance procedures for the equipment discussed in this section.

### 254-5.5 MAINTENANCE PROCEDURES

**WARNING**

**Before working on air ejectors, see section 8 of NSTM Chapter 505, Piping Systems .**

254-5.5.1 TROUBLESHOOTING GUIDE. Table 254-5-1 lists possible causes and suggested remedies for air ejectors that fail to maintain correct condenser vacuum.

254-5.5.2 STEAM SUPPLY. Dry steam at full operating pressure (as specified on the unit nameplate) must be continuously supplied to air ejector nozzles. If the steam pressure to the nozzles fluctuates, the pressure may be raised to about 15 pounds above the recommended operating pressure to prevent fluctuations from interfering with proper operation. Higher steam pressures will increase capacity only slightly and may even cause reduced capacity and overloading of inter- and after-condensers in some cases. High steam pressures also require uneconomically large quantities of steam.

**Table 254-5-1** AIR EJECTOR TROUBLESHOOTING GUIDE

| **Ejector Fails to Maintain Correct Condenser Vacuum** | |
|---|---|
| **Cause** | **Remedy** |
| Steam pressure at nozzle below recommended operating pressure | Raise steam presure to that stamped on the nameplate. |
| Steam superheat other than design value | Reduce superheat to rated value or increase the motive steam pressure above design rating until the vacuum improves. |
| Clogged ejector steam nozzle or strainer | Remove material clogging strainer or nozzle. |
| End of ejector steam nozzle restricted | Straighten dented nozzle, or replace with new nozzle. |
| Insufficient cooling water passing through inter<#0106>condenser causes overloading of second<#0106>stage ejector | Increase flow of cooling water by recirculating condensate. |
| Broken condenser tube | Plug or replace tube. |
| Leaky packing on condenser tubes | Tighten or replace packing. |
| Clogged drains on inter- or after-condenser causing flooding | Clean drains. |
| Excessive cooling water temperature | Lower water temperature by increasing flow. |
| Excessive air leakage into system | Inspect for air leakage source and eliminate leakage. |
| Leaking sentinel or inter-stage valves | Replace valves. |
| Recirculation of air due to faulty loop seal | Close valve to condenser until seal again fills with condensate. |
| Nozzle or diffuser eroded or corroded | Remove parts and check throat for size and evidence of erosion. Replace worn parts. If frequency of replacements is too high, determine the cause. |
| Leakage between inter-and after-condenser | Replkace sealing gasket. |

254-5.5.3 STEAM STRAINER. During the first few months of operation of a newly connected unit, inspect the steam strainer at least once a month and remove all foreign matter. Inspect once every 2 years thereafter, or whenever there is reason to believe the strainers are fouled. In some installations the gages which indicate the steam pressure at the ejector nozzles are actually connected to the system at a point ahead of the strainers. If the strainers become clogged, therefore, the air ejector may be malfunctioning because of low steam pressure at the nozzles even though the pressure gages show full steam pressure. Paragraph 254-5.4.4 includes precautions for avoiding burns when cleaning strainers.

254-5.5.4 RECIRCULATION. Insufficient cooling water circulation through the inter- and after-condensers will result in loss of vacuum because the circulating water will be heated to the point where it does not condense the steam portion of the steam-air mixture entering the inter-condenser. The second-stage ejector, instead of handling only saturated air, must also compress some of the steam discharged into the inter-condenser from the first-stage ejector element. This results in overloading of the second-stage ejector.

254-5.5.4.1 Insufficient cooling water is indicated by an abnormally high reading on the air ejector cooling water discharge line thermometer and by overheating of the ejector assembly and the atmospheric vent line. These temperature rises are caused by uncondensed second-stage motive steam. The maximum discharge cooling water temperature can be found in the manufacturer's technical manual or drawings. Adjust recirculation to the condenser (NSTM Chapter 255, Volume 1) so that cooling waterflow through the ejector assembly is sufficient to keep the discharge water temperature at or below the maximum.

254-5.5.4.2 Avoid recirculating excessive quantities of water to bring the cooling water discharge temperature below the maximum allowable temperature. This constitutes an unnecessary and uneconomical loss of heat from the system. Keep all thermostatically controlled recirculation valves in proper operating condition and adjusted to automatically control the amount of water recirculated (NSTM Chapter 255, Volume 1).

254-5.5.4.3 If automatic valves are not provided, control recirculation manually or by installing properly sized orifices in the recirculating lines. This limits the flow of recirculated water to that actually required under standby and low-power operation. Discontinue recirculation as soon as power increases to where recirculation is no longer necessary.

254-5.5.5 UNLOADING VALVE. In certain installations, only part of the condensate flows through the air ejector inter- and after-condensers at high condenser loads. The rest of the condensate flows around the air ejector through a bypass line in which a spring-loaded unloading valve is installed. An improperly adjusted valve may cause insufficient flow through the air ejector regardless of the amount of recirculated condensate. Adjust the bypass line valve so that under normal operating conditions the temperature of the cooling water discharged from the air ejector does not exceed the maximum discharge temperature. The adjustment should also maintain the cooling water discharge temperature at 5 degrees to 10 degrees F below the maximum allowable temperature under standby conditions while condensate is being recirculated (and under cruising conditions when no recirculation is required). No further adjustment should be required for other operating conditions giving maximum operating economy.

254-5.5.6 VALVE LEAKAGE. Leaky suction or discharge valves of idle or standby ejector elements will cause a loss of vacuum by overloading operating ejector elements. Leaks in such areas as the valve glands, gasketed joints, and relief or sentinel valves will also cause a vacuum loss for the same reason. Repair procedures can be found in NSTM Chapter 505, Piping Systems.

254-5.5.7 DIVISION PLATE LEAKAGE. If internal leakage occurs across the division plate between the after- and inter-condensers, the second-stage element will become overloaded because the air-steam mixture discharged by the second-stage element will leak back to the inter-condenser instead of being discharged to the atmosphere. This problem is rare in modern air ejectors. If it is suspected, however, hydrostatically test the inter- or after-condenser shell and inspect the drains for leakage. Repair by removing the condenser tubes, disassembling the unit, and replacing the internal gaskets.

254-5.5.8 TUBE LEAKAGE. Condensate flooding of the inter- or after-condensers from improper drainage or leaking condenser tubes can cause a loss of vacuum and improper system operation. Vacuum loss results from a decrease in the effective condensing surface because of flooding. Flooding may also cause condensate to be drawn into the second-stage element, with subsequent erratic operation of the unit. If flooding is suspected, inspect and clear the drain lines. If necessary, hydrostatically test the unit and examine it for tube leaks, either at the tube joints or through the tube walls.

**NOTE**

Copper-asbestos and Teflon-asbestos tube packing materials are no longer available. The following tube packing procedures apply to the new packing materials. Applicable equipment manuals should be modified to reflect this change in tube packing requirements.

254-5.5.8.1 Tube joint leaks at expanded tube ends can be repaired by rerolling the tubes (paragraph 254-2.6.4). Tube joint leaks at packed tube ends can be repaired by either tightening the ferrule slightly or by repacking the joint with new packing rings. All ship installations should use two rings of copper (Crane style 601EC), and one ring of Kevlar-Teflon (Crane style C-78K), installed in that order, with the Kevlar-Teflon ring installed last. Additionally, superheated steam plant installations may use one ring of copper (Crane style 601EC), one ring of lead (Crane style 601E), and one ring of Kevlar-Teflon (Crane style C-78K), installed in that order. (This combination of packing rings may provide better sealing than the combination of copper and Kevlar-Teflon rings.) Contact Naval Sea Systems Command (NAVSEA 03Z43) if there is difficulty in obtaining tight joints with any of the above packing material combinations.

254-5.5.8.2 If repacking is required, remove the old packing rings and install the new ones as outlined in paragraph 254-2.6.25. Copper rings should be set with a number of very light hammer blows on the caulking tool. (Copper does not flow readily into the packing box threads.) The Kevlar-Teflon ring should be installed last and secured by a ferrule.

254-5.5.8.3 Take special care to avoid necking or crimping the tubes when installing packing rings. Similar damage to tube ends can be caused by overtightening the ferrules.

254-5.5.8.4 Emergency repair of leaking tubes can be made by plugging both ends. If retubing or any other major repairs are necessary, hydrostatically test all parts of the air ejector to the pressures specified on the nameplate. Before the new tubes are installed, take special care to examine and put in proper working order all internal parts of the air ejector.

254-5.5.8.5 Make sure that the division plate gaskets between the inter- and after-condensers are tight before and after installing new tubes. Tube erosion near the diffuser discharges may be a problem with certain installations. If this trouble is suspected, remove a sample tube close to each jet discharge of the inter- and after-condensers and inspect for signs of erosion damage. If serious erosion is present, renew all tubes in the affected area and periodically inspect and renew tubes as necessary.

254-5.5.9 DIRTY CONDENSER. Loss of vacuum and erratic operation will result if inter- or after-condenser tubes become fouled with dirt, scale, or grease. This condition is rare where condensate is used as the cooling medium for the inter- and after-condensers.

254-5.5.10 NOZZLE AND DIFFUSER. If air ejector nozzles become eroded, deformed, or fouled, operating the equipment under high-vacuum conditions will be impossible. Eroded nozzles indicate that wet steam is being admitted to the equipment. If nozzle erosion is found, make sure that the steam supply lines are properly drained.

254-5.5.10.1 Excessive water in the motive steam will cause erratic operation of the equipment, particularly if the water flows intermittently to the nozzle. If strainers are not kept clean, the steam pressure differential through the strainer is likely to rupture the strainer basket, admitting dirt or scale to the nozzle which may clog. In some cases, nozzles may be clogged with grease, boiler compound, or other deposits, decreasing the efficiency of the jet.

254-5.5.10.2 The nozzle can usually be cleaned with a wooden stick, a soft copper wire, or the reamer provided as original equipment with some ejectors. Handle these carefully, and make sure that the proper reamer is used for each nozzle size so that the nozzle will not be damaged. If it is necessary to remove the nozzle for cleaning or replacement, take care that the internal surfaces are not damaged. Dents or deformation of the downstream end of the nozzle or rough scratchy surfaces in the throat or diffusing passages of the nozzle will cause improper equipment operation.

254-5.5.10.3 If foreign deposits are present on the internal surface of the nozzle or diffusers, remove them with special reamers or soft copper wire. Soaking in methyl chloroform will aid in removing grease deposits. If nozzle or diffuser replacement is required, make sure that the proper gaskets are used during reassembly. It is essential that the nozzle and diffuser tube be concentric and in proper alinement and that the end of the nozzle be the correct distance from the end of the diffuser. Consult drawings and technical manuals before disassembly or reassembly.

**NOTE**

First- and second-stage nozzles and diffusers are not interchangeable.

**WARNING**

**Never attempt to repair an on-line element. The resultant steam spray could cause severe burns. Before opening an element, isolate it from the assembly by closing the steam supply and interstage isolating valves.**

254-5.5.10.4 It is possible to clean or replace steam strainers, nozzles, and diffusers of an ejector element while the remainder of the assembly is operating. In installations where each element has separate inter- or after-condensers, isolating valves are not provided or required. In some cases, where a common after-condenser is provided for two second-stage elements, the internal construction of the unit is such that steam discharged from the operating element cannot readily back up through the diffuser of the other second-stage element. Isolating valves in the second-stage diffuser discharges are therefore unnecessary.

254-5.5.11 LOOP SEAL. If an air leak is present in the U-shaped loop seal provided for draining the inter-condenser, the air in the water column of the seal will lower the effective specific gravity. Maintaining a stable seal will thus become impossible. Occasionally, a sudden surge in vacuum or violent roll of the ship may cause water in the U-shaped loop seal to siphon out into the condenser. If this occurs, close the valve at the condenser end of the U-shaped loop seal for a few seconds and then open it slowly to re-establish the seal. A freshwater line is often provided for filling the seal.

254-5.5.12 RADOJET NOZZLE. The radojet nozzle, after being removed for inspection and cleaning, must be adjusted for satisfactory operation. To replace the nozzle point after removal, screw it all the way out to prevent its jamming against the nozzle. The gasketed joint should then be securely and finally made up since any subsequent change in this joint will change the nozzle point setting. Screw the nozzle point all the way in until it lightly touches the nozzle. Back it off 1/16 inch to obtain an approximate setting. Make final adjustments by measuring the vacuum with the condenser suction valve closed. Secure the nozzle point with its locknut in the place where the maximum vacuum is obtained. This vacuum, corrected for barometric pressure, should correspond to the value stamped on the nozzle point cap.

## REAR SECTION

### NOTE

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